DREDGED MATERIAL RESEARCH PROGRAM

TECHNICAL REPORT D-77-11

USE OF DREDGED MATERIAL IN SOLID WASTE MANAGEMENT

by

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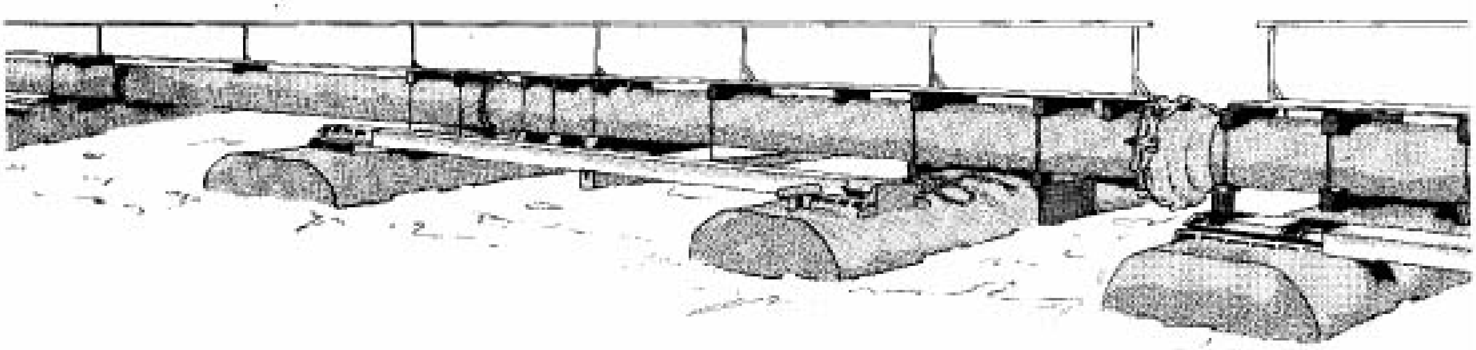

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1. The technical report transmitted herewith represents the results of one of several research efforts (work units) undertaken as part of Task 4C, Land Improvement Concepts of the Corps of Engineers' Dredged Material Research Program. Task 4C is part of the Productive Uses Project (PUP) and has as a general objective determination of the technical feasibility of enhancing nonproductive land with dredged material.

2. There has been a dramatic increase in the last several years in the amount of land disposal of dredged material, necessitated largely as a result of the need for confining dredged material classified as polluted or with potential for causing adverse environmental impacts. Land is continuing to become more and more scarce for disposal activities, and the problem becomes more acute with the need for selecting each new disposal area. Attention therefore can be profitably and justifiably directed towards concepts that can increase the service life of disposal areas and thereby reduce the need for additional facilities. The purpose of this particular study was to determine the feasibility of removing and using dewatered dredged material as soil in solid waste management to allow reuse of the initial disposal site.

3. The potential uses of dredged material at sanitary landfills were investigated and include cover, gas barriers and vents, impervious liners, and leachate collection underdrains. The suitability of dredged material for each of these uses was evaluated by comparing dredged material with the properties of soil known to be suitable for use in sanitary landfills. The basic findings are that in most cases dredged material can be considered a soil, and depending on its properties and the needs at the landfill, it can be used in solid waste management. Coarse-grained dredged material can be used for gas vents and leachate drains, and fine-grained materials can be used for gas barriers, impervious liners, and covers.

4. An additional intent of this study and report is to promote more widespread interest in and concern over the idea that dredged material can be considered a resource; in this case, a resource to be used in sanitary landfills. To this end, it is expected that the basic

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conceptual design and methodology described in this study may be of greater long-term significance to persons concerned with land-use planning and management rather than the specific landfill designs presented in the report.

John L. Cannon
JOHN L. CANNON
Colonel, Corps of Engineers
Commander and Director

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This report presents the results from an investigation of the feasibility of using dredged material in solid waste management. Potential uses investigated included the construction of cover, liners, gas vents, leachate drains, and gas barriers at sanitary landfills. The properties of dewatered dredged material were compared with those of similar types of soil, and the suitability of dredged material to fulfill the functional requirements of various uses of soil at solid waste disposal operations was evaluated on the basis of the comparison. The

(Continued)

20. ABSTRACT (Continued).

suitability of slurry or semisolid dredged material was also evaluated.

This report discusses the environmental and economic factors that will influence the feasibility of using dredged material in solid waste management. How the different uses for dredged material can be coordinated with dredged material and solid waste disposal operations occurring simultaneously or sequentially at the same location are also discussed. Concepts are presented to suggest the types of operations that could result if dredged material were used in solid waste management.

The investigation concluded that dewatered dredged material can meet the functional requirements of several uses for soil at a sanitary landfill, that uses for semisolid dredged material are limited to situations in which trafficability is not a consideration, and that trench and area methods of sanitary landfilling are adaptable to the use of dredged material.

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SUMMARY

Because of the concern for the effects open-water dredged material disposal may have on water quality and benthic life, the Corps of Engineers (CE) has resorted more and more often to the land disposal of dredged material; land acquisition difficulties have increased accordingly. Similarly, solid waste management authorities have experienced increasing difficulties in acquiring land for solid waste disposal. This study investigated the feasibility of using dredged material in solid waste management from the standpoint that dredged material could be used to replace natural soil as borrow or to create land on which to locate solid waste disposal operations.

The uses for soil at sanitary landfills were investigated and include cover, gas barriers and vents, impervious liners, and leachate collection underdrains. The suitability of dredged material for each of these uses was evaluated by comparing dredged material properties with the properties of soils known to be suitable. It was concluded that coarse-grained dredged material is suitable for use to vent decomposition gases, collect leachate, and provide a trafficable covering when the infiltration of rainfall into the sanitary landfill is acceptable. Fine- or mixed-grained dredged material was shown to be suitable for a number of uses, including as a gas barrier, impervious liners, and cover. Dewatering is required to ensure that fine- or mixed-grained dredged material has the consistency of soil.

Economic and environmental factors will influence the use of dredged material in solid waste management. Economic advisability will be determined in part by a comparison between the cost of dredged material dewatering and that of purchasing borrow material. Dewatering costs could conceivably be shared by the Corps and solid waste management authorities because both agencies would benefit. Environmental factors will be site specific. Dredged material contamination must be considered but is not expected to be a significant problem when dredged material is used in a properly operated sanitary landfill. Sufficient information on which to base incisive guidance concerning the use of contaminated dredged material is not yet available.

Concepts for using large amounts of dredged material in solid waste management were developed. One concept shows how a single parcel of land might be used first as a dredged material containment area and then as a sanitary landfill by using a modified trench method of sanitary landfilling. Another concept, involving land creation using dredged material and hill construction by the area method of sanitary landfilling, demonstrates how dredged material can add flexibility to the management of solid waste. A third concept, for use long after a sanitary landfill has been completed, involves the injection of dredged slurry into the voids of a sanitary landfill to extinguish and prevent underground fires and to reduce subsidence by filling the voids.

For reference, Appendix A presents brief descriptions of the solid waste management operations discussed in this report. While most of Appendix A deals with sanitary landfilling, processes such as composting, shredding, and baling of solid waste are also described. Hydraulic dredging, dredged material containment, and dredged material dewatering are described briefly in Appendix B.

PREFACE

This report addresses the feasibility of using dredged material in solid waste management. Conducted between November 1975 and June 1976, the study was Work Unit 4C02 of the Dredged Material Research Program (DMRP), conducted for the Office, Chief of Engineers, at the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi. The study forms part of the DMRP Productive Uses Project (PUP), MAJ R. M. Meccia and Mr. T. R. Patin, past and present Project Managers, respectively.

The study was conducted by personnel assigned to the Environmental Engineering Division (EED) of the Environmental Effects Laboratory (EEL) at WES under the general supervision of Dr. John Harrison, Chief, EEL, and Mr. A. J. Green, Chief, EED. The work was under the direct supervision of Mr. R. L. Montgomery, Chief, Design and Concept Development Branch, EED. Principal investigator was Mr. M. J. Bartos, who wrote the report.

During the study, COL G. H. Hilt, CE, and COL J. L. Cannon, CE, were Commanders and Directors of WES. Technical Director was Mr. F. R. Brown.

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CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. Customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
inches	2.54	centimetres
feet	0.3048	metres
miles (U. S. statute)	1609.344	metres
acres	4046.9	square metres
cubic yards	0.7646	cubic metres
tons	907.185	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
pounds (mass) per cubic yard	0.59327631	kilograms per cubic metre
foot-pounds (force) per cubic foot	47.880339	joules per cubic metre

USE OF DREDGED MATERIAL IN SOLID WASTE MANAGEMENT

PART I: INTRODUCTION

Background

1. Because of environmental constraints associated with open-water disposal, Corps of Engineers (CE) Districts have increased their use of land-based containment areas for the disposal of dredged material. This increased dependence upon confined disposal areas and an increased awareness of the ecological value of coastal and riparian wetlands have contributed to difficulty in acquiring suitable land area for containment facilities. Mitigation of land-acquisition problems can be achieved by extending the service life of containment areas.

2. Research is currently under way within the Dredged Material Research Program (DMRP) to investigate procedures for the design and location of reusable containment areas. Such facilities would serve as processing centers to prepare dredged material for removal and off-site productive use. This would permit containment area reuse and would decrease land acquisition requirement in direct proportion to the volume of dredged material removed.

3. The Corps is not alone in its land-acquisition dilemma; agencies responsible for the management of solid waste are experiencing similar difficulties in obtaining suitable sites on which to operate environmentally sound solid waste disposal operations. A major portion of the solid waste generated in this country is ultimately placed on land in sanitary landfills. The location of a sanitary landfill is constrained in several ways, notably by cover material requirements and availability and by site characteristics related to potential adverse environmental impact. High water table areas are generally unsuitable for sanitary landfilling because excavation for cover material would bring solid waste too near the groundwater table, thereby increasing the possibility of contamination by leachate.

4. If dredged material could satisfactorily perform the functions of cover material, then sanitary landfills could be located at sites previously considered unsuitable due to a deficiency of native cover soil. Some solid waste operations might become economically attractive if large volumes of dredged material were available at low or no cost. For example, the location of large regional sanitary landfills on marginal land may be economically infeasible due to the high cost of purchasing and hauling borrow material for use as cover. The landfill location would become more economically attractive if suitable dredged material could be acquired free of charge and hauled to the sanitary landfill inexpensively enough to effect a reduction in the total cost of obtaining cover material.

Purpose and Scope

5. The purpose of this study was to investigate the feasibility of using dredged material in solid waste management and to identify and develop workable concepts for uses that appeared feasible. The feasibility of each concept was investigated by considering the functions required of the dredged material; comparing these functional requirements with the physical and engineering properties of dredged material; and studying operational procedures for obtaining, hauling, and placing the dredged material and solid waste. Multiple-use concepts, in which dredged material used with solid waste management is part of a larger overall operation, were presented from the point of view of the beneficial uses of dredged material.

6. Due to the site-specific nature of each solid waste management problem and of each dredged material containment operation, the details of each concept were left to local planners and designers. Special considerations to be made before using dredged material in solid waste management were cited.

Approach

7. The approach used in this study was to determine the types of dredged material suitable for use in conjunction with solid waste

management. Since dredged material is basically a soil mixture with an abnormally high water content that can be reduced, the substitution of dewatered dredged material for soil should be feasible. The properties of dewatered dredged material were compared with those of similar soils, and the suitability of dredged material to fulfill the functional requirements of various uses of soil at solid waste operations was evaluated on the basis of the comparison. In addition, the characteristics of dredged material disposal operations (material with a high water content, segregation of particle sizes, hydraulic transportation of material, the availability of large volumes of material, etc.) were investigated to devise innovative concepts for using dredged material in solid waste management.

8. To become familiar with the state of the art in solid waste management, a cursory literature review was conducted with special attention paid to the various ways of using soil. Additional assistance was obtained from personnel of the U. S. Environmental Protection Agency (EPA), who provided information concerning ongoing and recently completed demonstrations and innovative concept studies.

PART II: USES FOR DREDGED MATERIAL IN SOLID WASTE MANAGEMENT

9. Dredged material has several potential uses in solid waste management operations. There are several uses for soil in sanitary landfilling, and dredged material dried to near optimum water content for compaction has the physical and engineering properties of soil.[1] If composting gains widespread acceptance in the U. S., dredged material may find use as an admixture or as cover; therefore composting is discussed in this study.

10. For reference, Appendix A presents brief descriptions of the solid waste management operations discussed in this report. While most of Appendix A deals with sanitary landfilling, processes such as composting, shredding, and baling of solid waste are also described. In Appendix B, a brief summary of dredged material disposal is presented. Hydraulic dredging, dredged material containment, and dredged material dewatering are described briefly.

Uses in Sanitary Landfills

11. The potential uses for dewatered dredged material in a sanitary landfilling operation are as material for constructing cover, liners, gas vents, leachate drains, and gas barriers. Each of these uses is described below, along with a discussion of the suitability of dredged material for each use. Since no commonly accepted quantitative method for evaluating the suitability of a given material for performing the functions required for use is currently available, suitability is determined qualitatively. Some soil types are more suitable than others, but no specific physical or engineering properties are generally specified.*

Cover

12. Daily cover. At the end of each working day, or more

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* Personal communication, N. Schomaker, EPA National Environmental Research Center, Cincinnati, Ohio, 24 Feb 1976.

frequently if necessary, solid waste is covered with at least 6 in.* of compacted soil. Although presenting a sightly appearance is an important function, daily cover is designed to do more than simply hide solid waste. Table 1 lists the functional requirements of daily cover, and each is described below.

a. Vector control. A very important requirement of daily cover is the control of vectors, such as rats, flies, etc., at the site. Fly larvae (maggots) are often a part of municipal refuse and are buried with the solid waste. If the flies are allowed to hatch and emerge through the soil cover, they pose a serious health problem. A 6-in. thickness of compacted fine-grained soil has been shown to be effective in preventing fly emergence.[2] Conversely, granular material with large pore spaces is not effective.

   Rats and other rodents are also undesirable at a sanitary landfill and can be controlled by making the food (solid waste) unavailable to them. Rodents are capable of burrowing through soil in order to obtain the food buried underneath, so the cover must be capable of resisting rodent burrowing. Clean granular soils, sand, and gravel are effective in preventing rodent burrowing, because tunnels will continuously cave in.

b. Prevention of internal fires. The spontaneous combustion of solid waste can result in an underground fire. Fires can cause air pollution by the smoke released to the atmosphere, and the large voids caused by the burning can cause substantial subsidence and cave-ins. The soil covering the bottom and sides of a burning cell helps to confine a fire, but the top cover may become undermined and collapse, exposing the overhead cell to the fire. A carefully operated sanitary landfill will have no uncontrolled internal fires because the soil cover prevents oxygen from entering the cell. Fires can also be prevented by eliminating the formation of methane gas pockets. As methane gas is produced, it should be vented to the atmosphere, either directly through the soil cover or through special gas vents.

   If gas vents are used, then the cover should be impervious to gas flow, which is best performed by fine-grained soils with low permeability and high moisture-retaining ability. The use of clay must be carefully controlled so the clay does not dry out and crack. Sand and gravel with

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* A table of factors for converting customary units of measurement to metric (SI) units can be found on page 7.

Table 1

Functional Requirements of Daily, Intermediate, and Final Cover

Functional Requirement	Daily Cover	Intermediate Cover	Final Cover
Prevent fly and insect emergence	X	X	X
Prevent rodent burrowing	X	X	X
Minimize infiltration (dry state)	X	X	X
Maximize infiltration (wet state)	X	X	X
Minimize gas venting through cover*	X	X	X
Maximize gas venting through cover	X	X	X
Control oxygen movement	X	X	X
Minimize blowing paper	X	X	X
Assist vehicle support and movement		X	X
Resist erosion		X	X
Support vegetation			X

* If gas vents are provided.

considerable fines are also satisfactory in blocking gas flow, provided the gradation is suitable to form a dense cover with permeability significantly lower than that of the surrounding soil.

If gas is to be vented through the cover, and gas vents are not provided, then clean (little or no fines) sand and gravel are suitable. The use of granular soils to allow gas ventilation requires that the soils be kept drained, as water will impede or block the flow of gas.

c. Control of surface water infiltration. There are two philosophies concerning the control of surface water infiltration. Some believe that infiltration should be minimized to prevent leachate production, thus eliminating the need to collect and treat leachate. Others believe that infiltration should be maximized, arguing that the increased rate of decomposition and earlier site stabilization provide benefits exceeding the costs required to collect and treat leachate.

If the sanitary landfill is to be operated in the dry state, then the daily cover must be as impervious as possible. Silt and clay are generally impervious, and gravel and sand with considerable fines are also suitable to minimize infiltration. Clay layers must be kept moist to prevent cracking, however, as cracks extending through the clay will allow infiltration.

The maximization of surface water infiltration into the sanitary landfill requires that the cover be highly pervious. Clean sand and gravel are very pervious and are quite suitable. Uniform, poorly graded sand is generally more pervious than well-graded sand, but both are suitable provided there are little or no fines to fill the pore spaces.

d. Aesthetic considerations. Daily cover is also important from the standpoint of aesthetics. To promote public acceptance of a sanitary landfill, a neat appearance is essential; frequent covering of solid waste helps maintain an inoffensive-looking operation. Of special importance is the control of blowing litter. The EPA rates all soil types excellent for controlling windblown litter, although dry silt and fine sand may cause a dust problem.[3]

13. Intermediate cover. If a sanitary landfill is to consist of two or more lifts, the lifts must be separated by a 12-in. layer of soil called intermediate cover. Intermediate cover must fulfill all functional requirements of daily cover for up to 12 months and must be trafficable to assist vehicle support and movement. Provision for

all-weather operation must include a trafficable route to the working face. After the first lift is complete, the access routes are founded on the solid waste cells; the intermediate cover must be stable enough to support fully loaded solid waste delivery vehicles and compaction equipment.

14. While fine-grained soils can fulfill the functional requirements of daily cover, they are not well suited for traffic. Clay is especially poor in wet weather, becoming soft and slippery. The EPA suggests that an impermeable cover of fine-grained soil (to minimize gas and water flow) be supplemented by a layer of granular material suitable as a road base.[3] A carefully selected silty or clayey sand (or gravel) with enough fines to be impermeable may be trafficable in wet weather and may prove suitable for intermediate cover at a sanitary landfill operated in the dry state.

15. <u>Cover evaluation.</u> Table 2 shows the suitability of soil types for fulfilling the various functional requirements of cover material. The table shows that some soil types are suitable for meeting some functional requirements but not for meeting others. Therefore, the relative importance of each of the functional requirements must be determined so that the most suitable soil will be selected.

16. The characteristics of a desirable cover material are easy workability, moderate cohesion, and significant strength.[5] A mixture of sand, silt, and clay (SM or SC) has been shown to be a suitable cover material; if a gravel (GM or GC) is fairly well graded with 10 to 15 percent sand and 5 percent or more fines, it can make an excellent cover.[3] When compacted, granular coarse particles are held together by the binding action of silt and the cohesion of clay. The fines also serve to reduce the permeability. A well-graded silty or clayey sand or gravel (SM, SC, GM, or GC) will not develop troublesome shrinkage cracks, can control insects and rodents, and can be worked in most weather.

17. Well-graded silty or clayey sand or gravel is not always available, and a less-than-desirable material must often be used. In such cases the only soils that must be ruled out for use as cover are highly

Table 2

Suitability of USCS Soil Types as Daily Cover

General Soil Type	Unified Soil Classification System (USCS)*		Vector Control**		Infiltration Control†		Internal Fire Control				
			Prevent Fly and Insect Emergence	Prevent Rodent Burrowing	Minimize Infiltration (Dry State)	Maximize Infiltration (Wet State)	Minimize Venting Through Cover**	Maximize Venting Through Cover**,††	Control Oxygen Movement‡	Assist Vehicle Support and Movement‡‡	Minimize Blowing Litter**
Clean gravel	GW	Well-graded gravels or gravel-sand mixtures, little or no fines	P	G	P	E	P	E	P	E	E
	GP	Poorly graded gravels or gravel-sand mixtures, little or no fines	P	G	P	E	P	E	P	G-E	E
Clayey-silty gravel	GM	Silty gravels, gravel-sand-silt mixtures	F	F-G	F-G	P-G	F-G	P	F-G	G-E	E
	GC	Clayey gravels, gravel-sand-clay mixtures	F	F-G	F-G	P-G	F-G	P	F-G	G	E
Clean sand	SW	Well-graded sands or gravelly sands, little or no fines	P	G	P	E	P	G	P	G	E
	SP	Poorly graded sands or gravelly sands, little or no fines	P	G	P	E	P	G	P	F-G	E
Clayey-silty sand	SM	Silty sands, sand-silt mixtures	G	P	G-E	P-F	G-E	P	G-E	F-G	E
	SC	Clayey sands, sand-clay mixtures	G	P	G-E	P-F	G-E	P	G-E	P-F	E
Silt	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity	G	P	G-E	P-F	G-E	P	G-E	P-F	E
	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	G	P	G-E	P-F	G-E	P	G-E	P	E
Clay	CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	E§	P	E§	P	E§	P	E§	P-F	E
	CH	Inorganic clays of high plasticity, fat clays	E§	P	E§	P	E§	P	E§	P-F	E

Note: P = poor; F = fair; G = good; E = excellent.
* Further information on the USCS appears in Reference 4.
** Ratings are taken from Reference 3.
† Infiltration control is divided into wet and dry state considerations at the suggestion of EPA personnel.
†† Only if well drained.
‡ Rating based on rating to minimize gas venting.
‡‡ Ratings taken from Reference 4 which rates suitability of USCS soil types for use are road subgrade.
§ Except when cracks extend through the entire thickness.

organic soils (OH and OL) and peat (Pt). In using marginal soils, precautions must be taken to ensure that the landfill is operated in such a manner that the inability of the cover to meet one or more functional requirements does not result in a health or safety hazard.

18. Use of dredged material as cover. Dredged material exists as a slurry (10 to 20 percent solids) while being transported hydraulically to a containment area. Inside the containment area sedimentation occurs and the surface water is removed leaving a deposit of semisolid dredged material with a high water content. Surface evaporation causes the formation of a crust of dry material, which has a water content typical of natural soils. The dredged material beneath the crust remains at water contents near or exceeding the liquid limit of the material. The three simplistic states of dredged material, slurry (10 to 20 percent solids), semisolid (water content near or exceeding liquid limit), and dried crust (with water content typical of natural soil) are illustrated in Figure 1; more detailed information pertaining to dredged material disposal is presented in Appendix B.

19. The use of dredged material as a slurry or as a semisolid presents many operational and suitability problems. Due to difficulty in handling slurry and semisolids, especially when compacting or working on slopes, the use of dredged material in these forms is considered generally not feasible. Neither slurry nor semisolid would remain on the sloped working face, and drying the material would involve periods of time during which the surface would be unworkable. Leachate problems would probably result unless the water released from the dredged material into the solid waste were carefully controlled. Compaction of the material would be impossible until the material had dried to a consistency near that of a soil. There are also other problems with the use of slurry and semisolid dredged material, such as delivery to the site, on-site handling, storage, etc.

20. The use of dried dredged material as cover is operationally feasible, because the material can be easily hauled, spread, and compacted by conventional earth-moving equipment. Other research conducted under the DMRP showed that dried dredged material can be compacted to

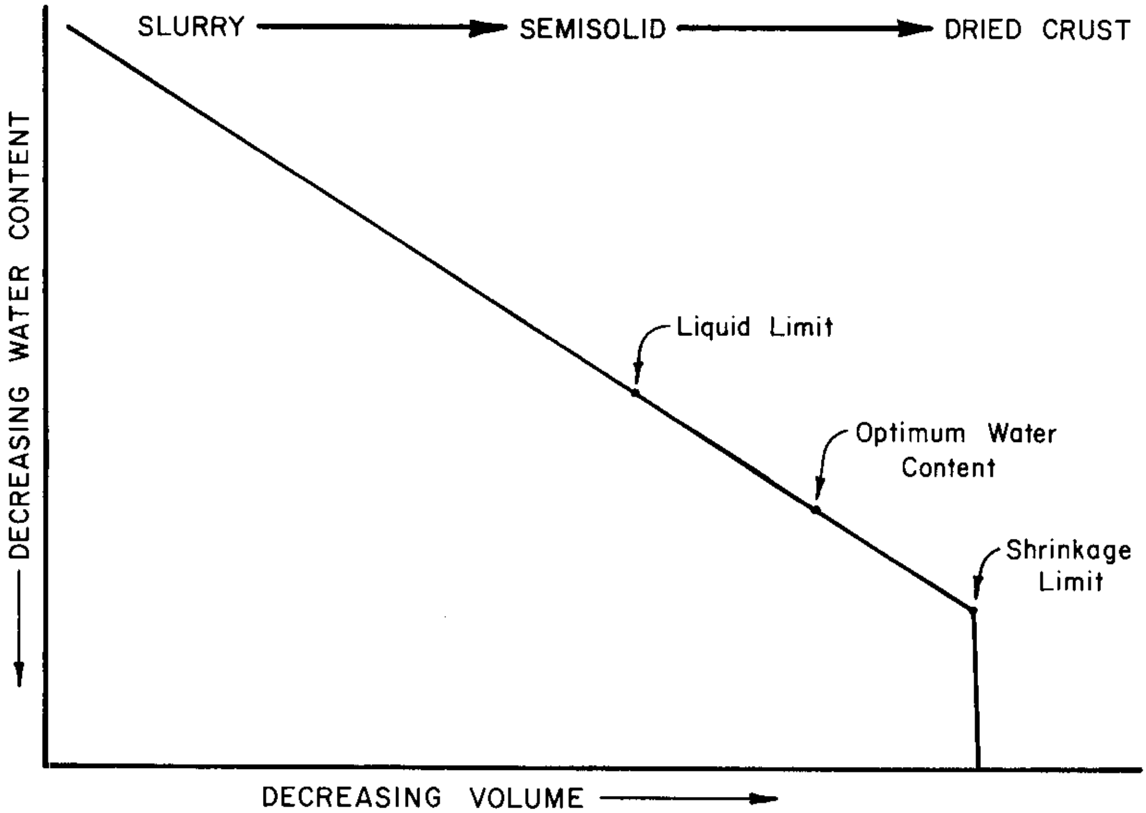
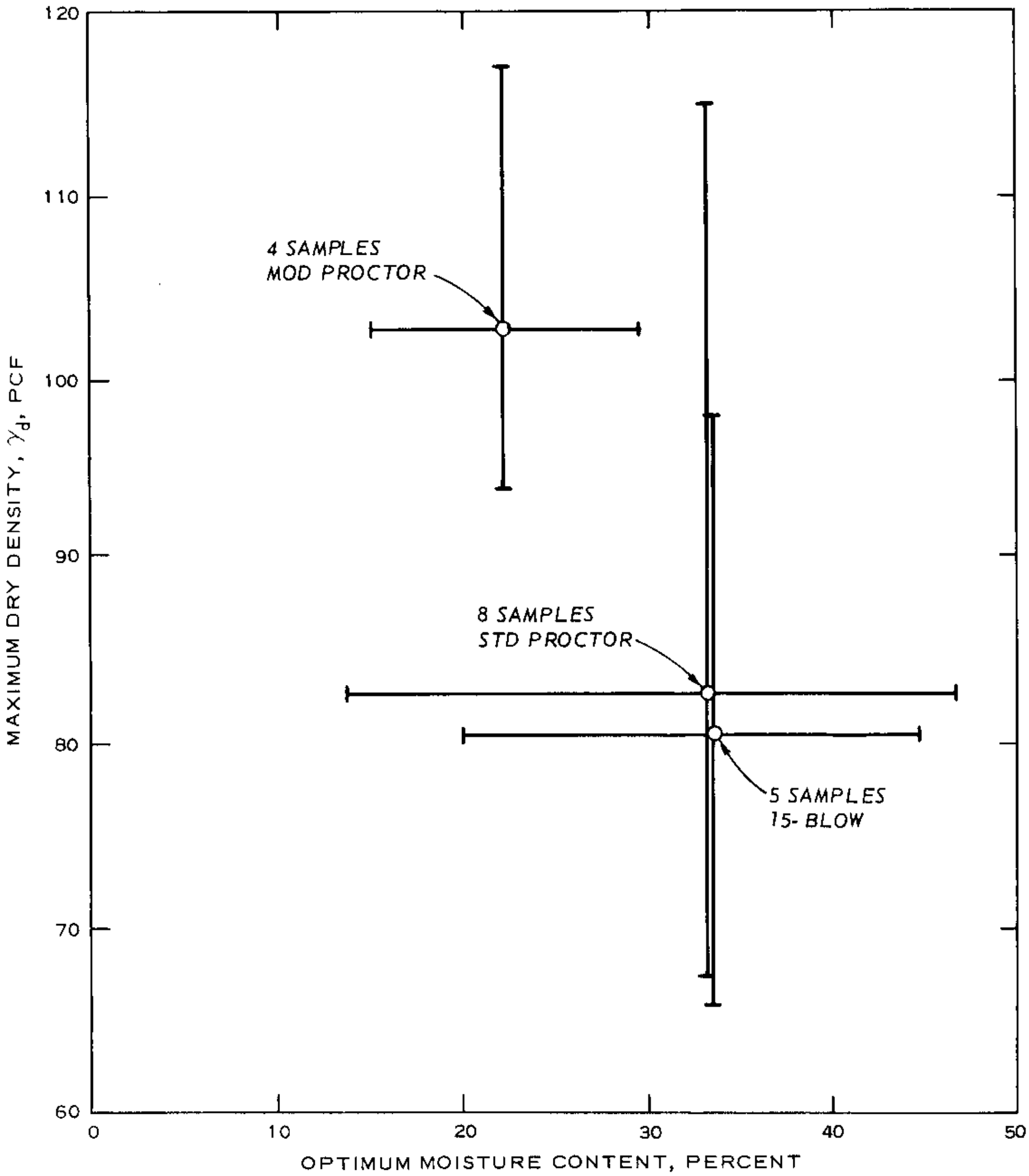


Figure 1. Dredged material consistency

dry densities comparable to those of natural soils by a reasonable compactive effort.[1] Figure 2 summarizes the results of those compaction tests.

21. Dry dredged material is available in the form of a surface crust at most dredged material containment areas. Alternatively, the dredged material may be dewatered by any of a number of processes currently being investigated under the DMRP. Further information on crust formation and dredged material dewatering is presented in Appendix B.

22. To evaluate the suitability of a particular deposit of dewatered dredged material, samples of the material should be classified according to the USCS.[1,4] To classify a sample by the USCS is simple and inexpensive, requiring only a grain-size analysis and a determination of the liquid and plastic limits of fine-grained material. Using the resulting classification, the suitability of the dredged material



TYPE TEST	COMPACTIVE EFFORT FT-LB/CU FT	NO. OF SAMPLES	MAX DRY DENSITY PCF	OPTIMUM MOISTURE CONTENT PERCENT
15 - BLOW	7,400	5	65.9 - 97.9 (80.6)*	20.0 - 44.1 (33.5)
STANDARD PROCTOR	12,200	8	67.4 - 115.0 (82.9)	13.7 - 46.8 (33.2)
MODIFIED PROCTOR	56,000	4	94.0 - 117.0 (102.8)	15.0 - 29.5 (22.3)

* AVERAGE VALUES SHOWN IN PARENTHESES.

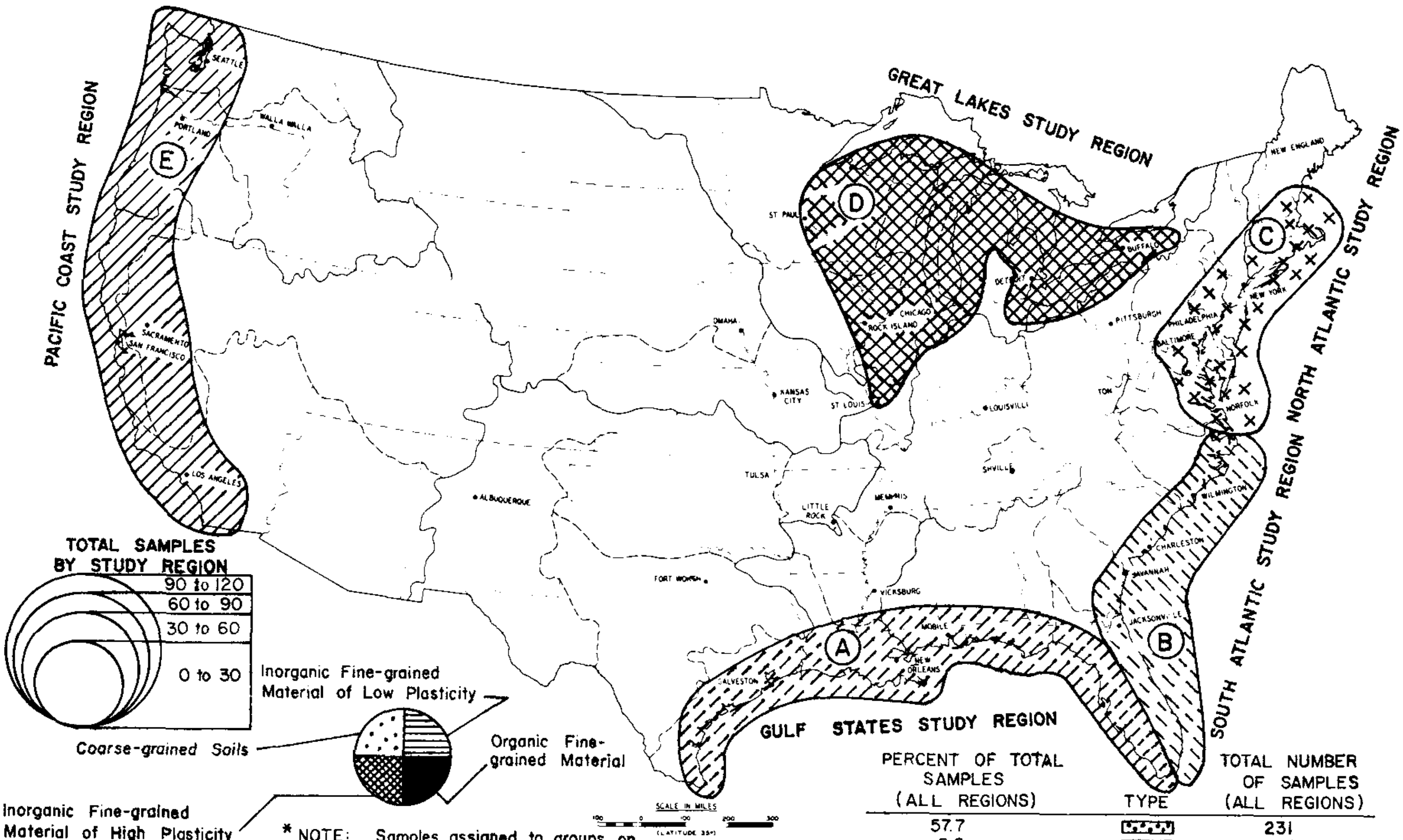
Figure 2. Average maximum dry density versus average optimum moisture content of dredged material samples

can be determined by comparing the classification of the dredged material with the suitability of that soil type using Table 2. Figures 3 and 4 show the types of material dredged throughout the U. S. These figures show that dredged material suitable for use as cover is available in all regions where dredging is done.

23. Covering shredded solid waste. Since shredded solid waste can often be placed without daily cover,[6,7,8] it may be possible to use semisolid dredged material to act as an intermediate cover at a landfill of shredded solid waste. The minimum compacted thickness for intermediate cover is 12 in. The use of semisolid dredged material with a high water content would involve placing an initial thickness greater than 12 in. so that the material would be 12 in. thick after dewatering and compaction. The initial thickness required to construct a final layer of satisfactory density can be easily determined using fundamental soil mechanics. The initial thickness would be equal to the final thickness (12 in.) plus the thickness lost during compaction plus the thickness lost in dewatering.

24. Access to covered portions of the shredded waste landfill would be severely restricted while the dredged material was drying. This would necessitate careful planning of the operation so that when one lift was completed, enough of the cover would have dried and been compacted so that the next lift could be started without interruption. If the cover was to be placed as sections of a lift were completed, then a dike might be required to contain the dredged material until it dried.

25. Semisolid dredged material may also be used as final cover at a shredded landfill. The greater thickness of final cover would require that the dredged material be placed in several lifts to dry. This in turn would delay ultimate site use. Earlier site use could probably be achieved by constructing retaining dikes and placing the final cover in one lift. After a period of time the surface of the dredged material would have stabilized sufficiently for nonvehicular uses. Vegetation could be planted to accelerate the drying rate of the dredged material and to enhance the aesthetic value of the site.



PERCENT OF TOTAL SAMPLES (ALL REGIONS)	TYPE	TOTAL NUMBER OF SAMPLES (ALL REGIONS)
57.7		231
5.8		23
30.7		123
5.8		23
TOTAL 100 %		TOTAL 400 SAMPLES

* NOTE: Samples assigned to groups on basis of first letter of USCS classification

Figure 3. Types* of dredged material sampled, by region

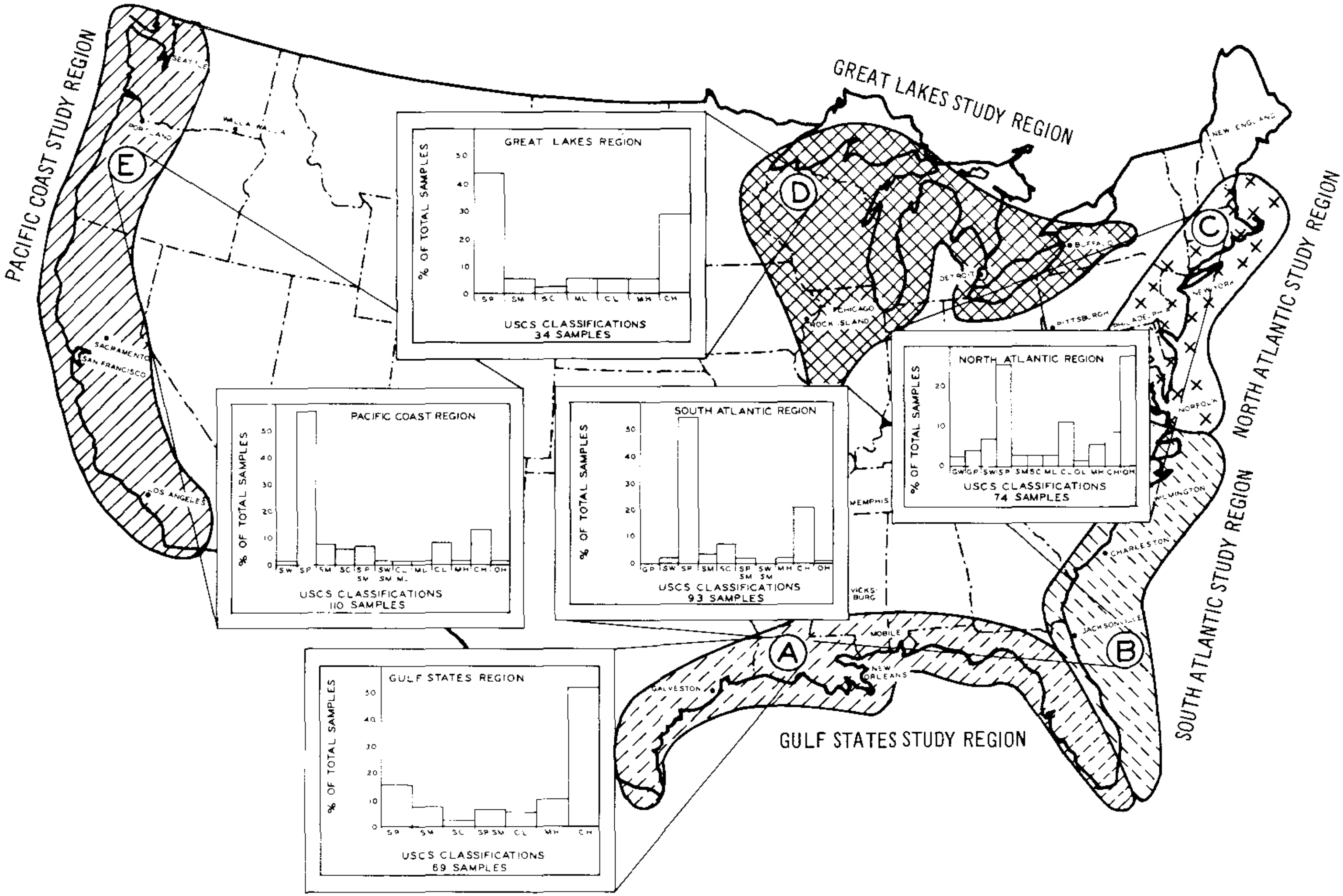


Figure 4. Distribution of dredged material types, by region

Gas and leachate barriers

26. As solid waste decomposes under anaerobic conditions, gases such as methane and hydrogen sulfide are produced. Methane is highly explosive when mixed with oxygen and can build up in culverts and building foundations. Hydrogen sulfide, while not produced in such great quantities as methane, is toxic even in low concentrations and has an obnoxious odor. To prevent the development of health and safety hazards near sanitary landfills, these decompostion gases must be confined laterally to the boundaries of the sanitary landfill.

27. Water seeping through solid waste can become contaminated. The contamination of surface and groundwater by contaminated water seeping from solid waste (leachate) must be averted either by collection and treatment or by prevention of its production. The use of dredged material to construct barriers to gas and leachate flow is described below.

28. Gas barrier wall. The prevention of the lateral migration of decomposition gases from within a sanitary landfill is ensured by the construction of a vertical barrier (Figure 5). Such a barrier is generally constructed by excavating a narrow trench (1 to 4 ft, typically)

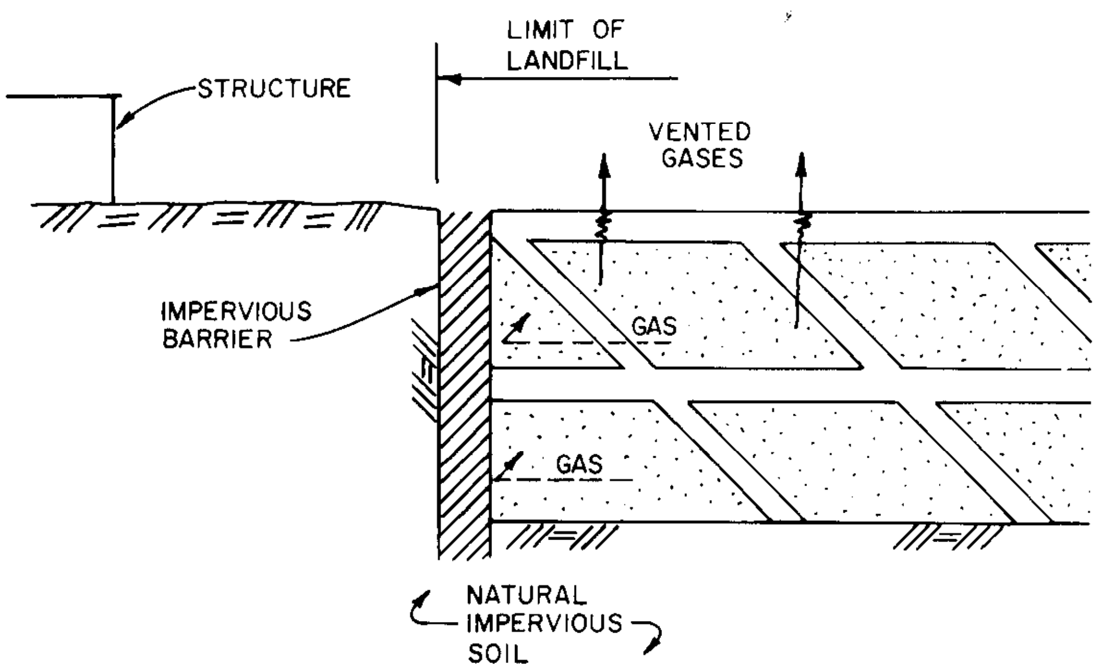


Figure 5. Perimeter gas barrier

around the sanitary landfill to a depth below the lowest solid waste. The trench is backfilled with impervious soil, compacted, and saturated with water. Keeping the barrier completely saturated is important to prevent the soil from cracking and to keep the pore spaces filled with water to prevent gas from leaking through.

29. Liner. An impervious liner (Figure 6) is designed to help reduce leachate production by preventing groundwater from entering the landfill. Additionally, leachate produced by infiltrating surface water is contained within the landfill and cannot contaminate groundwater. If a significant amount of leachate is produced, collection and treatment of the leachate is necessary to prevent inundation of the solid waste.

30. Since a liner is impervious and extends from beneath the solid waste to the surface, it also serves as a barrier to the lateral flow of gases. The requirements of a barrier wall must also be met by the liner if it is to block gas flow. This generally means that the liner must be kept saturated at all times.

31. One commonly used liner material is clay soil, carefully compacted to form a membrane 1 to 3 ft thick, completely sealing the

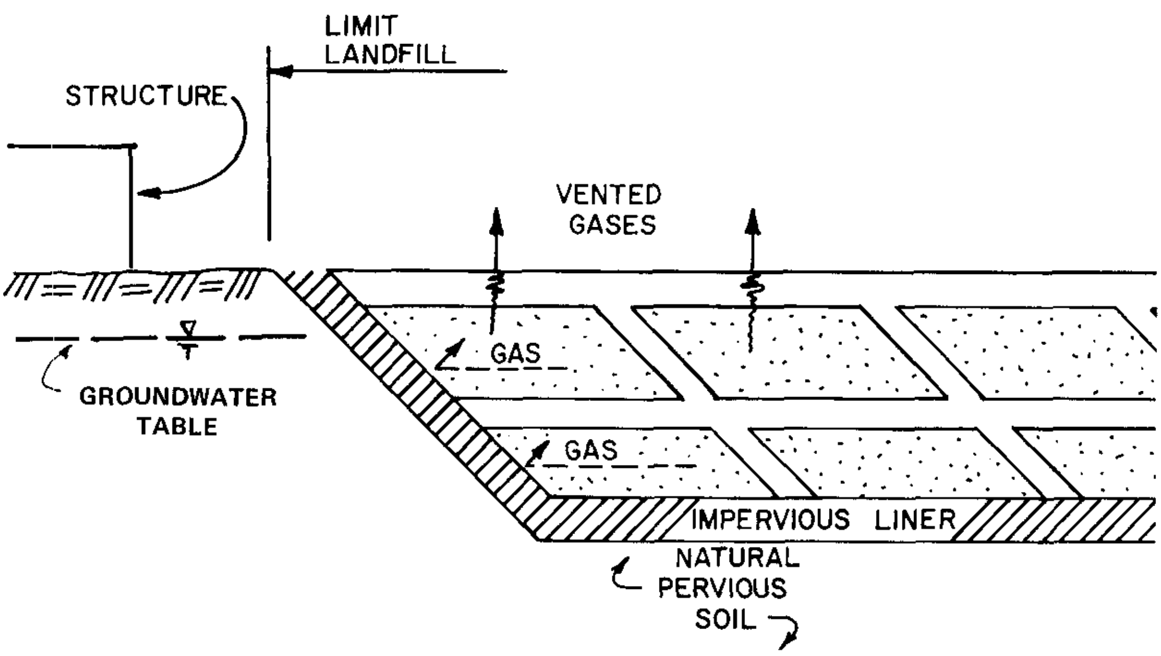


Figure 6. Impervious liner

bottom and sides of the sanitary landfill.[9] As in the case of gas barrier walls, liners must be kept moist to prevent shrinkage cracking. Unfortunately, the long-term effects of leachate on the structure and permeability of clay under anaerobic reducing conditions are not known.[9]

32. Suitability of dredged material. The suitability of a given material for use as a barrier to the flow of gas and water is determined by the permeability of the material. The flow of water through soil is greatly dependent on the size, shape, arrangement, and gradation of particles. Fine-grained dredged material samples compacted at water contents near optimum have been shown to be practically impervious to water with values of the coefficient of permeability typically near 10^{-8} cm/sec.[1] The use of fine-grained dredged material would require that the material be dewatered to near optimum moisture content and then carefully compacted, because dredged material with a high water content has a higher void ratio and therefore a higher permeability. In addition, if large amounts of water were included in the liner, this water would be gradually squeezed out by the weight of the solid waste. If the pore water of the dredged material contained contaminants, they could have an adverse effect on groundwater quality. Careful control of water content and compaction will prevent problems of this nature.

33. The permeability of dredged material to gas is much the same as the permeability to water and is influenced by the same properties (grain size, shape, etc.). One other consideration is involved, however, and that is the amount of moisture present in the pore spaces. If the dredged material is not saturated with water, then some gas can flow through the open soil pores. Interstitial water acts as a barrier to gas, and a saturated, fine-grained dredged material would present an effective barrier to gas flow.

34. While the use of dredged material to line a sanitary landfill would require the use of dredged material dewatered to near optimum moisture content, semisolid dredged material could be suitable for constructing a gas barrier wall. As long as the wall was kept wet, the semisolid dredged material would prevent gas flow. While the void ratio and permeability are greater for semisolid dredged material than for

dredged material that has been dewatered and compacted, the water in the voids would prevent the flow of gas. Dredged material classified CL or CH according to the USCS is likely to be suitable for use in constructing a liner or gas barrier.

Gas vents and leachate drains

35. Barriers to the movement of gas and leachate are designed to contain the gas and leachate within the boundaries of the sanitary landfill. Gas vents (Figures 7-9) are used to direct the flow of gas to the atmosphere where it is harmlessly dissipated, and leachate drainage layers are used to intercept leachate and drain it to an area where it

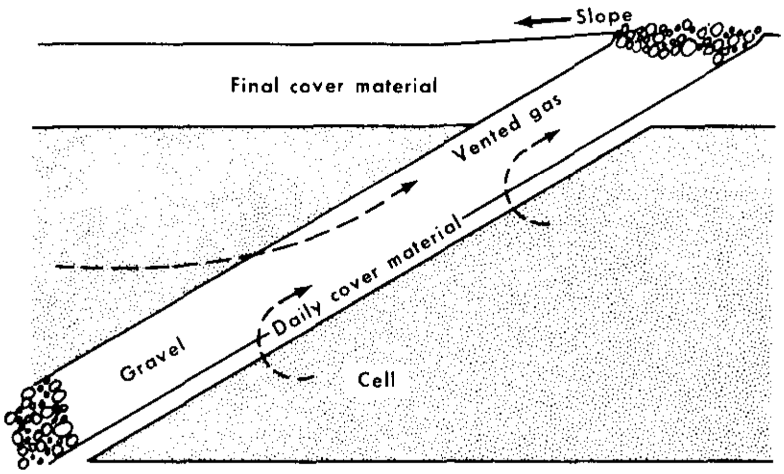


Figure 7. Gravel vent[3]

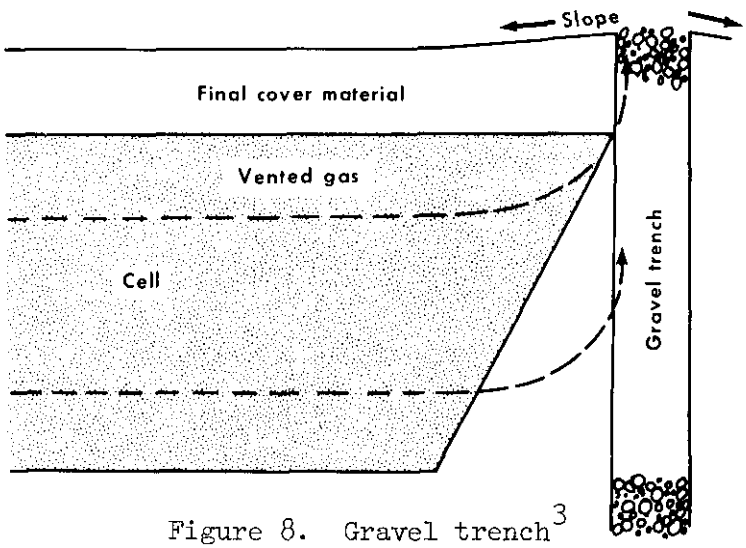


Figure 8. Gravel trench[3]

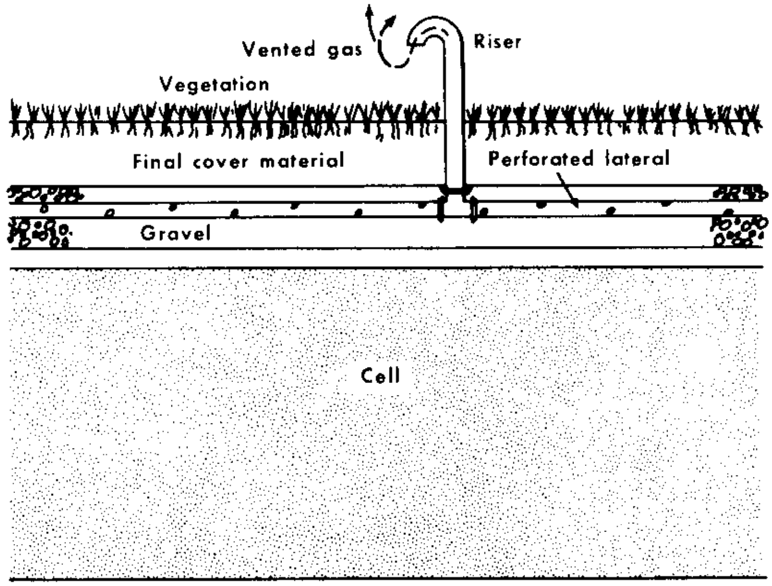


Figure 9. Horizontal gravel layer with vent pipes[3]

can be collected for treatment or recirculation. A leachate drainage blanket can also be used to vent gas if the blanket extends to the surface as shown in Figure 10.

36. The controlled ventilation of gas requires that the vent be much more pervious than the surrounding soil, and a leachate drain must also be very pervious so that leachate will be drained quickly away from the solid waste. If drainage is too slow, leachate may back up and inundate the solid waste. To be suitable for venting gas or draining leachate, the dredged material must consist of sand or gravel with little or no fines (GW, GP, SW, SP) and must be much more pervious than the soils on the site. Since coarse-grained dredged material is highly pervious and drains freely, no dewatering is required prior to use.

37. During a disposal operation the coarse-grained fraction of the dredged material is deposited near the discharge pipe in the containment area with other undesirable material often mixed in. For example, clay balls and miscellaneous trash will fall out of suspension with the sand and gravel. In order to use the sand and gravel, removal of unwanted material by screening may be necessary. However, in most cases suitable coarse-grained dredged material can be borrowed directly from a dredged material containment area without such processing. The availability of such material has been verified by researchers

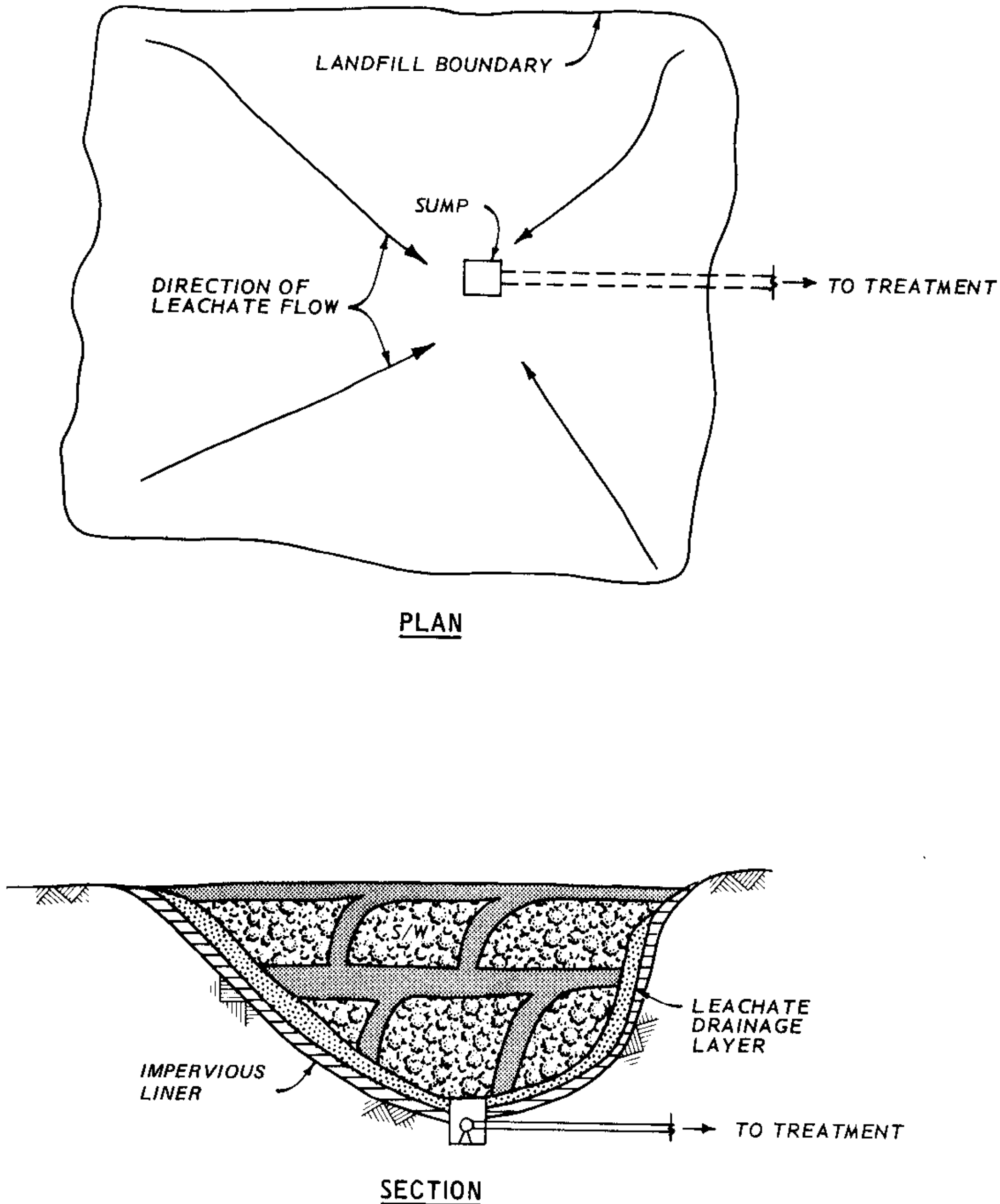


Figure 10. Liner and leachate drainage blanket used to collect leachate for treatment (from Handbook of Solid Waste Disposal: Materials and Energy Recovery by Pavoni, Heer, and Hagerty, 1975 Litton Educational Publishing, Inc. Reprinted by permission of Van Nostrand Reinhold Company)[5]

investigating Corps practices in the confinement of dredged material.[1,10]

Uses in Composting

38. The uses of dredged material in conjunction with a composting operation are severely restricted for two basic reasons. First, the composting process itself does not require soil or soil-like material; second, composting is not widespread in the U. S. If a market for compost develops, however, composting may become a viable solid waste management technique. For this reason, two potential compost-related uses are presented here.

39. One use involves the admixture of dredged material in a semisolid condition into windrows of shredded solid waste. Such dredged material would have to be carefully selected for high available nitrogen and water contents. The purpose of adding the dredged material is twofold: the nitrogen is required to lower the carbon-nitrogen (C:N) ratio of the compost to an acceptable value and the water is used to adjust the moisture content. Additional benefit may accrue in the form of increased mechanical strength, caused by the solid particles of dredged material. On the other hand, the dredged material would fill void spaces within the compost windrow, and this would increase the turning required to prevent formation of an anaerobic condition.

40. This concept is not considered especially attractive to municipalities. The sludge produced at wastewater treatment plants has been successfully used to adjust both the nitrogen and water contents of compost. This arrangement is more convenient to local officials because the entire operation can be coordinated by one level of government, as opposed to coordination requiring the interfacing of local authorities with Federal government (Corps of Engineers). Also, using sludge alleviates the municipality's sludge disposal requirements.

41. Dredged material could also be used to cover a landfill of composted solid waste. Such cover would have to meet the functional requirements of cover at a conventional landfill until more information concerning the environmental impact of composted landfills is developed.

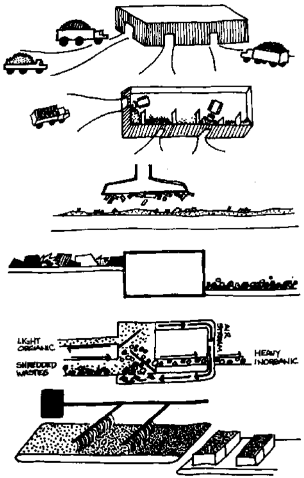
The production of decomposition gases would not be a concern, because decomposition (aerobic) would have been completed during composting. Leachate may be a problem; however, little information is available to support or deny this.

42. The use of dredged material in conjunction with a compost landfill was suggested in another DMRP report by Reikenis et al.[11] This concept calls for layers of composted solid waste to be covered with dredged material (Figure 11). Such a landfilling operation could be feasible provided the area being filled was laterally confined to prevent the lateral flow of dredged slurry. The composting operation itself would be located outside the landfill site, as the soft dredged material and the compost would not provide a suitable base for the windrow turning equipment. Again, leachate may be a problem.

Economic Factors

43. The success of any attempt to use dredged material in solid waste management will be dependent upon the economic feasibility of the project for each of the agencies concerned. To ensure cooperation among agencies, the benefit-cost ratio must be favorable $b:c \geq 1$ for each agency. Restated, there should be a positive net benefit $b-c > 0$ for each agency. Since each operation involving the use of dredged material in solid waste management will be unique, economic feasibility must be evaluated on a case-by-case basis. The following paragraphs describe economic factors that influence the b:c ratio of projects involving the use of dredged material in solid waste management. The factors are the costs of dewatering, purchasing, and hauling dredged material; purchasing and hauling borrow material; providing additional dredged material storage capacity; and site improvements required to excavate and haul dredged material. Each of these factors (listed in Table 3) can be assigned a dollar value by appropriate agencies, although some costs may not be involved in every operation.

The Bay Area need not continue to bury its solid wastes in land fills. Instead, it could start now to recover these resources and put them to beneficial use. The twelve steps involved in such a resource recovery process are the following.......



1. Deliver All Wastes To A Processing-Transfer Station

To the greatest possible extent paper, glass, and metals would be kept segregated at their sources and be delivered in separate trucks.

2. Separate Out Directly Useable Materials

Returnable bottles and clean paper would be sorted out for resale and reuse, either directly or after reprocessing, as raw materials for new secondary industries.

3. Remove Ferrous Metals For Sale To Industry

Large ferrous metal objects such as stoves or car bodies would be segregated by hand. Tin cans and other small iron objects would be extracted magnetically.

4. Reduce Particle Size

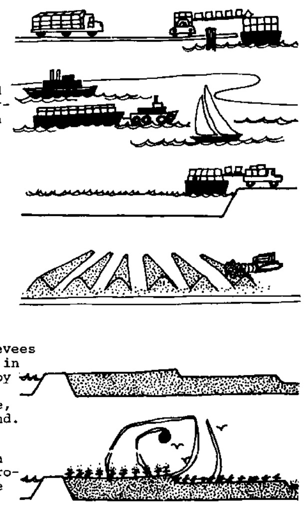
Materials remaining after the above would be shredded and crushed to reduce all materials to small particles with a maximum dimension of two inches.

5. Separate Organic From Inorganic Materials

The shredded wastes would be passed through an air classifier - a device that uses a rising stream of air to lift the light organic material and leave the heavy inorganic material behind.

6. Blend In Special Wastes

Special organic wastes such as digested sewage sludge, which is high in nitrogen and water content, would be blended with the main stream of shredded organic material.



7. Load Organic Wastes On Barge For Transport

Blended wastes, packaged in special containers, would be trucked to the point of embarcation and transfered to barges.

8. Transport Organic Wastes To Delta Island

Containerized organic wastes would be transported by barge from San Francisco Bay through the waterways of the Delta to the steadily subsiding Delta Islands.

9. Unload Organic Wastes On Delta Island

Barge unloading operations, being carried on in windy locations, would be carefully designed to minimize the scattering of wind-blown particles as well as the creation of any unsightliness.

10. Compost Organic Wastes

Wastes would be stacked in windrows for aerobic composting with regular turning. Composting would be continued until a stable humus has been produced. High temperatures would prevent fly breeding and rodent attraction.

11. Using Compost, Raise The Land Level Behind The Levees

Compost would be placed on the land behind the levees to a width of 500 ft, each successive layer 1 ft in depth. Each layer of compost would be followed by a layer of suitable dredged material and the two thoroughly mixed to a depth of 20 ft at the levee, terracing downward toward the center of the island.

12. Plant Agricultural Crops On The New Land Surface

The nationwide importance of the entire operation is the demonstration that a soil mantle can be produced using compost, which is the equal of native soil in fertility. Hence, a 3- to 5-year period of rotating crops will be demonstrated using normal practices.

Environmental Impact Planning Corporation 319 Eleventh Street San Francisco California 94103

Figure 11. A resource recovery plan for the San Francisco Bay area[11]

Table 3

Factors Influencing Economic Feasibility of Using Dredged Material in Solid Waste Management

Economic Factors	Unit of Expression	Distribution of Costs and Benefits*		Remarks
		Costs	Benefits	
Additional storage capacity gained by removal of dredged material from containment area	Value of additional storage capacity, $/cu yd		D	Value of additional storage is the cost of obtaining storage by the least expensive method (dike raising, dewatering, etc.)
Cost of dewatering dredged material	$/cu yd	S and/or D		Dewatering costs could conceivably be borne by both agencies, depending on local conditions
Cost of site improvements required to permit transportation of dredged material to existing transportation facility	$ - lump sum	S and/or D		May not be required in many cases
Cost of purchasing dredged material	$/cu yd	S	D	Dredged material could be donated by District (see Reference 12), in which case there is neither cost nor benefit
Cost of hauling dredged material	$/cu yd/mile	S		Cost of hauling equal amounts of borrow and dredged material are expected to differ only when haul distances differ
Cost of purchasing borrow	$/cu yd		S	Benefit is cost saved by using dredged material
Cost of hauling borrow	$/cu yd/mile		S	Benefit is cost saved by using dredged material

* D: cost/benefit accrues to District.
S: cost/benefit accrues to solid waste management agency.

Factors affecting solid
waste management agencies

44. The economic feasibility of using dredged material as a substitute for borrow material in solid waste management is determined by comparing the costs of using borrow with the costs of using dredged material. The economic feasibility of using dredged material can be estimated by identifying the costs of using borrow as benefits (cost savings) and comparing these benefits with the costs of using dredged material. Factors (costs) contributing to the total benefits will be the costs of purchasing, excavating, and hauling borrow. The costs of stockpiling, spreading, and compaction cannot be claimed as benefits because these costs will be the same for an operation using dredged material.

45. Factors that will contribute to the cost of an operation using dredged material will depend on local conditions. Costs may include dewatering, purchasing, site improvements, excavating, and hauling. Dewatering costs could be borne wholly or in part by the District if economics are favorable, as will be discussed in the next section. Purchase price will depend upon the ownership of the dredged material and other constraints; an investigation of the sale or donation of dredged material has been conducted under the DMRP.[12] Site improvements may or may not be required and include the construction of an access road to the containment area, etc. Excavation and transportation costs will be similar to those associated with using borrow material. The costs of excavating and hauling dredged material will differ from those of excavating and hauling borrow when the borrow pit and the containment area are not at the same distance from the solid waste disposal site.

Factors affecting Districts

46. Generally, the sale or donation of dredged material would not involve any cost to the District, and the benefits would be the value of the additional storage capacity created by the removal of dredged material from a containment area. However, since the dredged material generally would require dewatering before use, solid waste management agencies may be discouraged from using dredged material because of the

costs of dewatering. In some cases the dewatering costs, or some fraction thereof, might be borne by the District as an inducement for solid waste authorities to use the dredged material. If the District contributes to the cost of dewatering the dredged material, then the costs would be the amount spent by the District for dewatering. The benefits would be the value of the additional storage capacity created by the consolidation of the dredged material due to dewatering and by the removal of the dry material by the solid waste authority.

Case Histories

47. Dredged material has been successfully used to cover sanitary landfills in the past. The following operations are cited to lend credibility to using dredged material in solid waste management and to serve as examples of how cooperation between authorities can result in mutual benefit. New Castle County, Delaware, acquired a filled containment area from the Philadelphia District and is currently using part of the land as a sanitary landfill.[13,*] This landfill, which involves the use of 120 acres for the disposal of shredded and unshredded solid waste, has been operating for 2-1/2 years. Dredged material in excavated at the rate of 300 tons per day from the remainder of the containment area for use as cover. Since the dredged material is unsuitable to assist and support traffic, 200 tons per day of select borrow are hauled in. The dredged material is hauled and spread for $1.64 per cu yd, while the borrow is hauled and stockpiled for use for $2.30 per cu yd.

48. In 1965 a sanitary landfill in Toledo, Ohio, was covered with a layer of hydraulically placed sand. The sand, 5 ft thick, was covered with topsoil, and the landfill was landscaped and is now the Detwiler Municipal Golf Course.[14] The reasons for using the hydraulic sand fill were said to be "related to availability, drainage, and stability. This material was dredged from the bottom of the adjacent bay

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* Personal communication, Albert W. Madora, Newark, Del., 14 June 1976.

and did provide the above mentioned advantages. To my knowledge there have not been any problems resulting from ... water involved in the filling operations."*

49. The American Public Works Association reported the following: "New York City has developed a process for converting sand obtained by dredging into cover material by inundating (ponding) the surface of the sand with digested sewage sludge (about 95% liquid). After a drying-out period, the sand and sludge are thoroughly mixed by mechanical plowing. The result is excellent cover soil obtained much more economically than if material had been imported."[15]

50. Bay City, Michigan, provided the Detroit District with a containment area on Middleground Island in the Saginaw River, and the District has used this site on a continual basis since 1973.** Between dredging operations, the city removes the dredged material for use as cover for a nearby sanitary landfill. The material is sandy (SP, SM, or SC), and between 100,000 and 150,000 cu yd of the material is used each year. Figure 12 shows a truckload of the dredged material being removed from within the containment area for use at the sanitary landfill.

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* Personal communication, Frank Duane, Golf Course Architect, Toledo, Ohio, 21 May 1976.

** Personal communication, Donald L. Billmaier, U. S. Army Engineer District, Detroit, 14 Feb 1975.

Figure 12. Dredged material being removed from containment area for use to cover sanitary landfill (courtesy Detroit District)

PART III: CONCEPTS FOR THE DISPOSAL OF SOLID WASTE AND DREDGED MATERIAL AT THE SAME SITE

51. Some potential uses for dredged material in solid waste management were discussed in Part II. Implementation of these ideas will require cooperation between the Corps of Engineers and solid waste management agencies, and this cooperation can result only if benefits to both parties can be shown. This part of the report is intended to point out to solid waste managers some advantages of the use of dredged material over the use of borrow and to show that cooperation in such endeavors can be beneficial to the Corps. The part will show how the different aspects of dredged material disposal and solid waste management can be coordinated at the same site, either simultaneously or sequentially.

52. Advantages to solid waste management agencies will be attributed mainly to the lower acquisition costs and greater availability of dredged material compared with borrow material. Clearly, dredged material cannot compete with natural soil available at or near the site, but if material must be obtained and transported to the site, or if operations require large amounts of material, dredged material may be more attractive than borrow material.

53. Corps benefits will relate to increases in disposal capacity. Local authorities may be more inclined to grant easements and other permissions required for the use of lowland sites near dredging operations if the site for a solid waste disposal operation can be created thereby. This would help ease the land acquisition problems of the Corps and would increase containment area capacity by the removal of dredged material. If the dredged material is removed for use in solid waste disposal operations, then land acquisition problems will be reduced proportionately.

54. The remainder of this part presents some concepts for using dredged material in solid waste management. One concept shows how a single parcel of land might be used first as a dredged material containment area and then as a solid waste disposal site using a modified trench method of sanitary landfilling. Another concept is land creation

using dredged material and subsequent hill construction using the area method of sanitary landfilling. This concept demonstrates how dredged material could add flexibility to the management of solid waste. A third concept is for use long after a sanitary landfill has been completed and involves the injection of dredged slurry into the voids of the sanitary landfill to extinguish and prevent underground fires and to reduce subsidence by filling the voids.

55. These concepts are presented in very general terms to demonstrate the types of operations that can be involved when dredged material is used in solid waste management. The presentation is necessarily qualitative, and detailed engineering design and carefully managed operation will be required to ensure the success of any such ventures. The two construction concepts are flexible in themselves; many variations of each concept, as well as combinations of the two, are certainly possible to meet local conditions.

Land Raising and Subsequent Sanitary Landfilling

Limitations

56. The principles of sanitary landfilling in dry land (land well above the water table) are widely practiced and well documented.[3] However, sanitary landfilling in wet areas (areas where the water table is near the surface) is generally avoided due to the additional problems of operating in wet conditions. However, the increasing difficulty of land acquisition for sanitary landfilling may someday require the use of high water table areas.

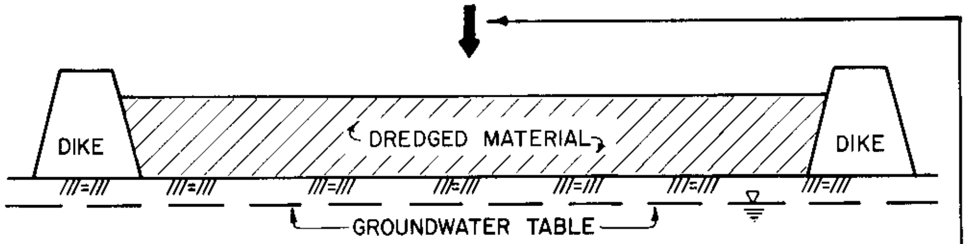
57. Sanitary landfilling in high water table areas is not generally an environmentally prudent undertaking due to the near certainty of water contamination by leachate and due to the difficulty of obtaining enough cover at the site. In addition, foundation conditions are generally poor, causing difficulties in equipment operation. The operation of sanitary landfills in wet areas should include provisions to alleviate poor working conditions caused by water and soft soil and to prevent solid waste and leachate from coming into contact with ground water or surface water.

58. One way to help prevent the interaction of water and solid waste is to keep the solid waste well above the water table at all times; this may be accomplished by permanently lowering the water table, but the cost of this is prohibitive. Alternatively, the land surface may be raised further above the water table prior to beginning the sanitary landfill. The use of dredged material to raise the elevation of the area above the water table and subsequently to provide a site for a trench method sanitary landfill may prove to be an economical way to utilize high water table areas as sanitary landfills. The following concept is presented to suggest one way that dredged material containment and solid waste disposal could be accomplished at the same location by using the land area first for a dredged material containment area and then for a sanitary landfill.

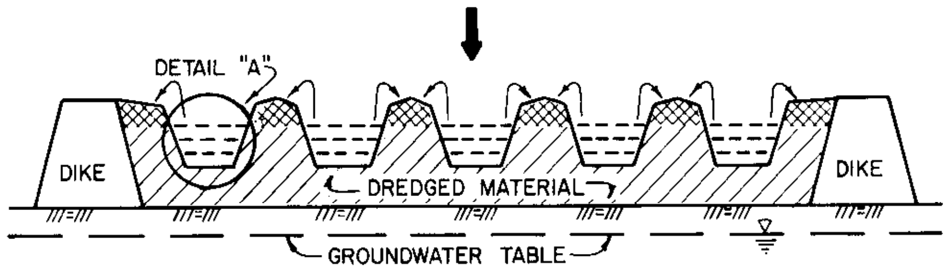
Modified trench method

59. The modified trench method involves the dewatering of dredged material by a program of progressive trenching and the subsequent filling of the trenches with compacted solid waste. The operational cycle consists of four basic steps, and cycles are repeated until the final elevation is reached. The first step is to construct a containment area, fill it with dredged material, and decant surface water. Second, a program of surface trenching, currently being evaluated under the DMRP,[16] is used to dewater the dredged material. The third step is to fill the trenches with compacted solid waste, and the fourth step is to raise the dikes in preparation of a second cycle. The modified trench concept is illustrated in Figure 13.

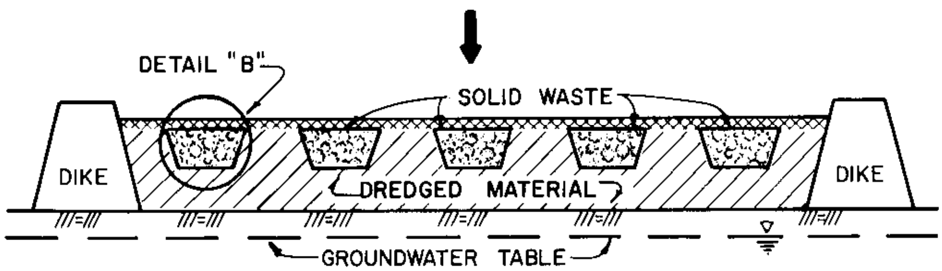
60. Step 1: Fill containment area. The first step, filling the containment area with dredged material and decanting surface water, serves to form the land base on which the sanitary landfill is to be located. The material is placed to a depth that will provide adequate separation between the solid waste and the groundwater table (see Detail B, Figure 14). Any coarse-grained material that becomes segregated within the containment area should be removed and stockpiled for future use to vent decomposition gases or drain leachate. If the needs for a sanitary landfill are immediate, the area could be subdivided, so that



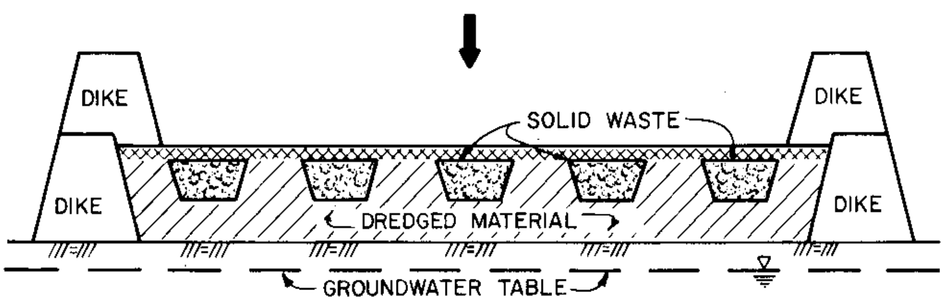
STEP 1: Fill containment area with dredged material and decant surface water.



STEP 2: Progressive Trenching - Excavate trenches for surface drainage; deepen trenches as material stabilizes.

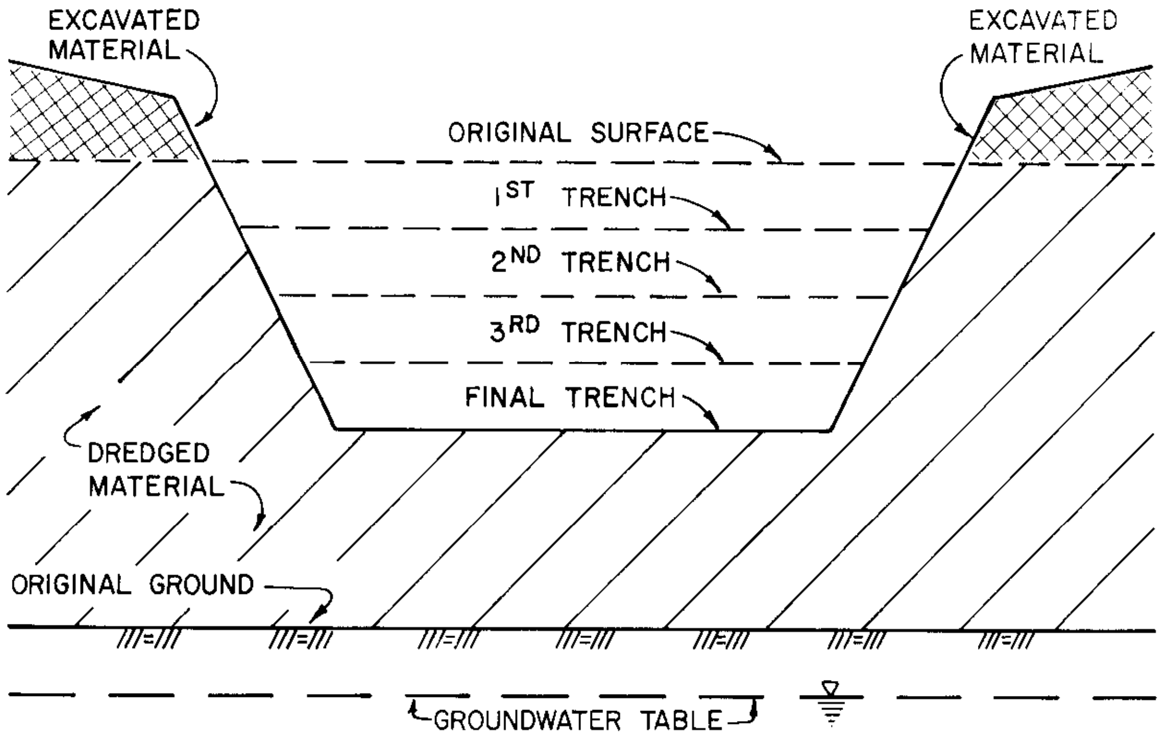


STEP 3: Sanitary Landfilling - Fill trenches with solid waste using dredged material excavated from trenches as cover.

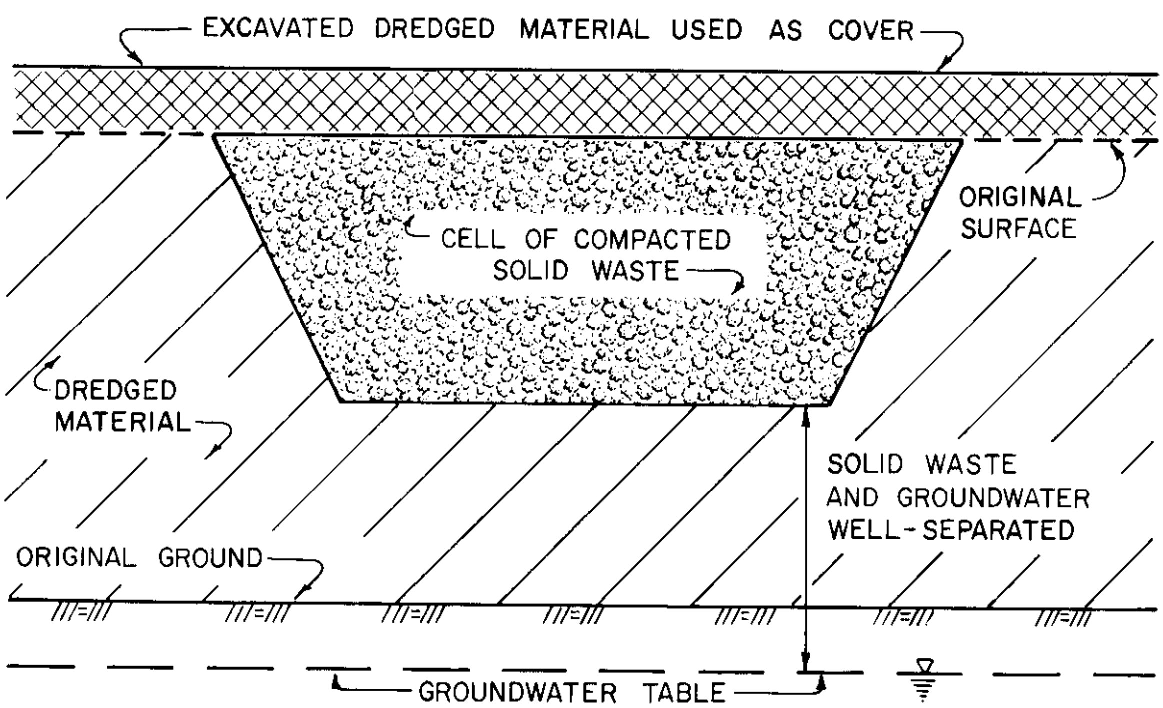


STEP 4: New Cycle - Raise dikes and repeat Steps 1-3 as many times as possible.

Figure 13. Construction procedure for modified trench method of sanitary landfilling (Details A and B are shown in Figure 14)



Detail A, Progressive trench excavation



Detail B, Trench filled with solid waste

Figure 14. Details of modified trench method (see Figure 13)

Step 2 could be started on part of the area while other parts are being filled.

61. Step 2: Progressive trenching. Progressive trenching serves two purposes: the trenches provide surface drainage so that the dredged material can dry by evaporation, and the completed trenches can be filled with compacted solid waste. Trenches are excavated from each containment area outlet, extending across the entire area, and are deepened incrementally as shown in Detail B of Figure 14. Trenching equipment, trench sizes and location, etc., have been described in other DMRP research reports.[16,17] If the groundwater table is high, then trench excavation should be limited to a depth that will result in adequate separation of solid waste and groundwater. Prior to placing solid waste in the trenches, liners, leachate drains, gas vents, etc., should be constructed as necessary.

62. Step 3: Sanitary landfilling. After the trenches have been fully excavated, they are filled with solid waste. The waste should be placed and compacted in thin layers to ensure that the maximum amount of solid waste is placed in each trench. At the end of each day, the compacted solid waste is covered with the dredged material previously excavated from the trench. When the trenches are filled, an intermediate cover of dredged material is spread and compacted, and the site is graded in preparation for the next lift of dredged material. If no further dredged material is to be placed into the containment area, the site can be used as a sanitary landfill using the area method of operation.

63. Step 4: Preparation for next cycle. To create additional dredged material storage capacity, the dikes are raised as the sanitary landfilling nears completion. Using the dried dredged material excavated from the trenches, the dikes are raised to a height that will be adequate to confine the next lift of dredged material. Once the site has been graded and the dikes have been raised, a new lift of dredged material is placed and the cycle (Steps 1-3) is repeated. Cycles are repeated until the capacity of the site is reached, or until it is no longer needed.

Solid Waste Hill Construction

64. In an effort to increase the efficiency of sanitary landfills in disposing of solid waste, some cities have built hills of solid waste.[18,19,20] The amount of solid waste that can be disposed per unit area of land increases with the vertical thickness of the solid waste, and hills constructed of many lifts of solid waste permit the disposal of more solid waste than do conventional sanitary landfills of low relief. Unfortunately, the amount of cover material available within economical haul distance of the site often restricts the number of lifts and, therefore, efficiency. The availability of large quantities of dredged material suitable for use as cover can greatly increase the efficiency of a sanitary landfill, and an operation of this type is described in the following paragraphs.

65. The concept described in the following paragraphs is a modification of a project successfully completed by the city of Virginia Beach, Virginia, and reported in EPA publication SW-52d.[19] Land acquisition difficulties and increasing property values in Virginia Beach hindered the establishment of a critically needed new sanitary landfill, so the city decided on the construction of a hill of solid waste at the existing sanitary landfill site. An ambitious plan was developed in which a 65-ft hill would be constructed using the area method of sanitary landfilling; the completed 162-acre site would be converted to a recreation complex. The existing cells of covered solid waste were used as the foundation for the hill, and solid waste disposal was never discontinued in the conversion to hill construction.

66. The concept is presented to show how dredged material might be used to create a large land area (Figure 15) that could serve multiple purposes (Figure 16). The first step is foundation development in which the area is surrounded by a perimeter dike and divided into several sections by interior dikes. Sections are filled with dredged material according to a sequence developed to take local conditions into consideration. After one section is filled, it is allowed to stabilize sufficiently for light recreation. Dikes in the interior are used as access

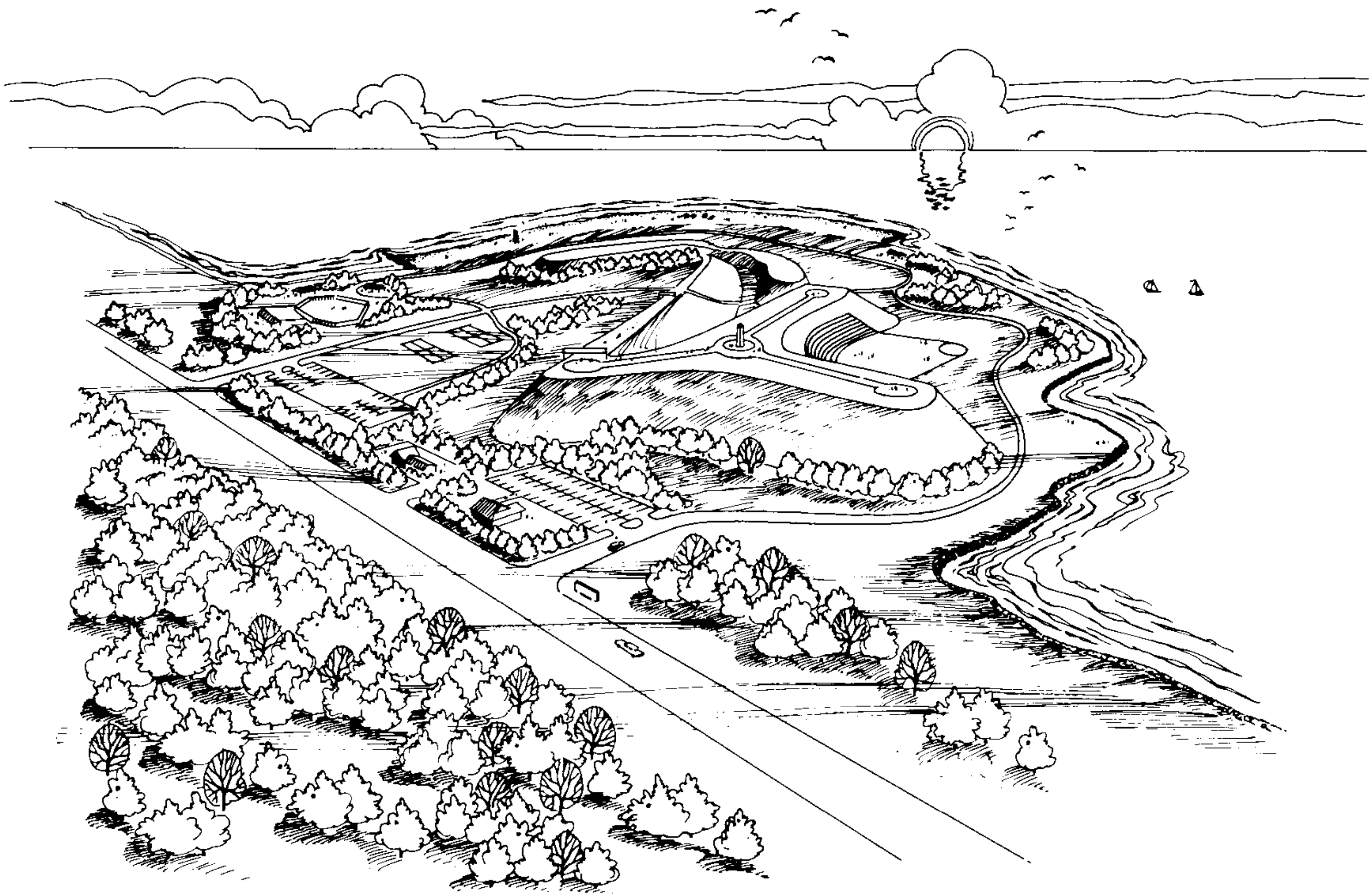


Figure 15. Rendering of completed project[19]

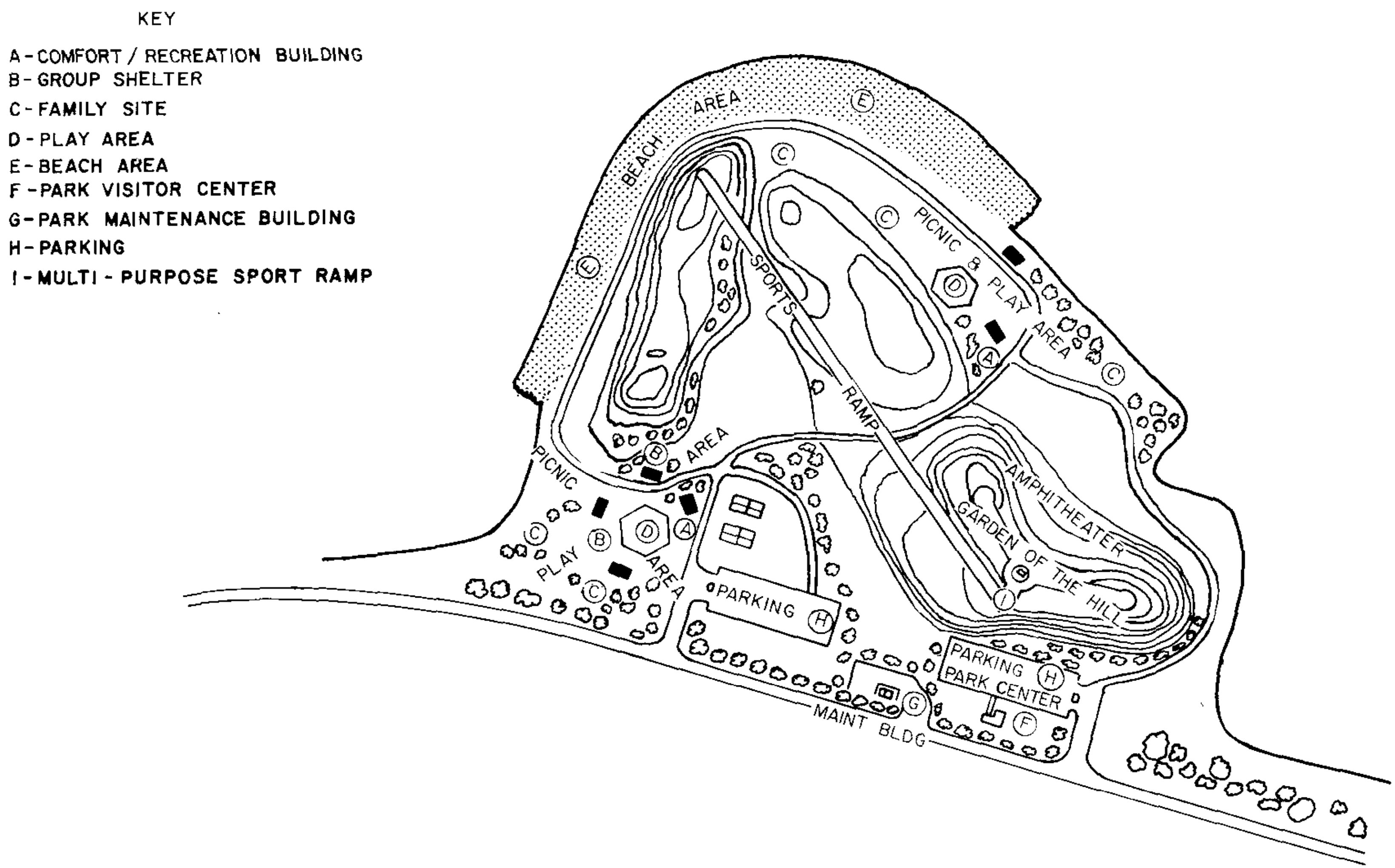


Figure 16. Layout plan of completed project[19]

roads for delivery and earth-moving vehicles during construction of each of three solid waste hills. After the solid waste hills are completed, the entire site is landscaped for recreational use.

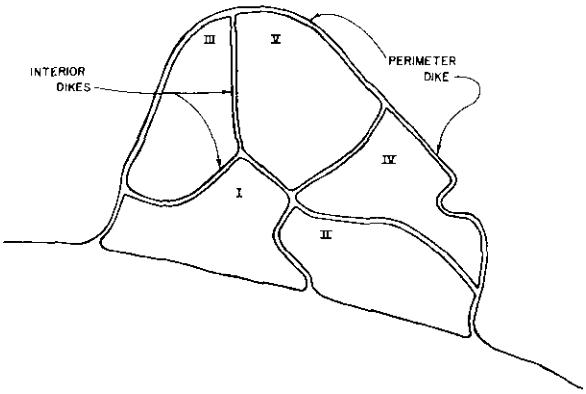
Foundation development

67. The foundation for such a concept could be a diked dredged material containment area in which the two primary construction operations are retainment dike construction and area filling sequence.

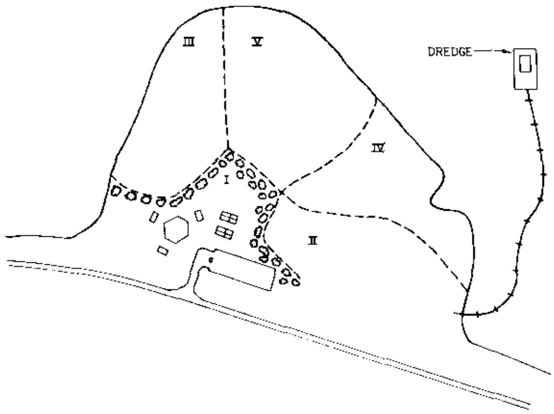
68. Dike construction. Two types of dikes are required during the creation of land for this concept: a perimeter dike to enclose the entire area and interior dikes to divide the area into sections to facilitate phased construction. The perimeter dike is designed to contain all dredged material for the life of the site, even after sanitary landfilling is complete. The perimeter dike also serves to protect the site from erosion possibly from current or wave action. Interior dikes are placed to permit a flexible filling schedule. An additional function of interior dikes is to provide access routes within the area when the dredged material is too soft to support men and vehicles. Dike crests must, therefore, be wide enough to provide two-way truck traffic. Figure 17 shows one possible interior dike arrangement. The sections shown provide for easy access to the proposed location of the solid waste hills and, therefore, a substantial portion of the recreation facilities can be put into use as soon as possible.

69. Filling sequence. Any number of schemes could have been used to subdivide the area. Similarly, many different filling sequences could be used. The order of filling for this particular hypothetical operation was based on the desire to establish a portion of the recreation area as soon as possible. The recreation area should be planned to include only very lightweight structures, as the dredged material may take long periods of time to develop sufficient strength to support significant loads.

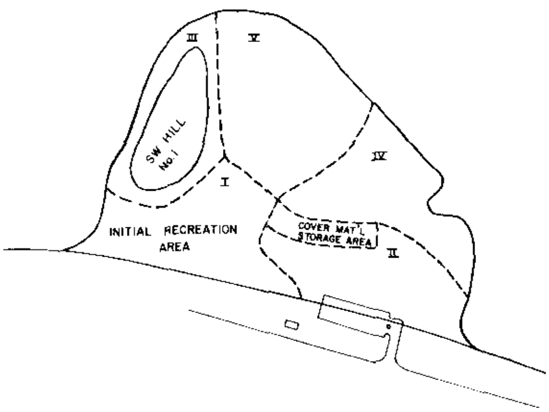
70. While the dredged material in Section I is drying, the other sections can be filled in the sequence given in Figure 17. Sections need not be completely filled one at a time; thin lifts will actually speed drying. Thin lifts could be tempered with the expeditious filling



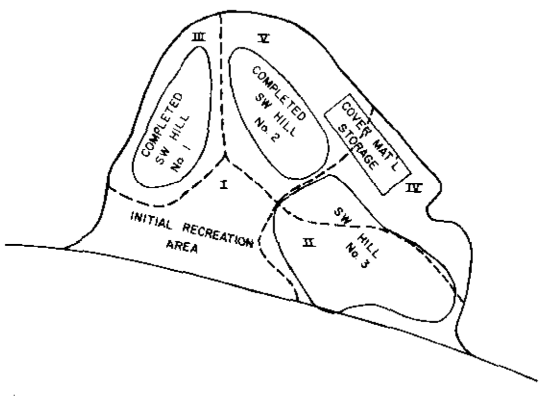
PHASE I: DIKING - Area is divided into several sections so that some parts may be used for recreation or sanitary landfill while other sections are being filled. Dike crests may ultimately serve as trails and roadways. Sectioning and filling sequence are determined by factors such as dredging schedule, specific features of site use, location of roads, required stabilization time, etc. Roman numerals show a filling sequence that was based on road location and immediate need for recreation area. Other filling sequences may be more suitable, depending on local conditions.



PHASE II: LAND CREATION AND INITIAL RECREATION AREA - As soon as the dredged material in Section I has stabilized sufficiently, part of the recreation area can be constructed while other sections are being filled. Planting of trees and other landscaping will separate recreation area from further dredging and sanitary landfilling operations.



PHASE III: BEGINNING OF SANITARY LANDFILLING - Most sections must be filled prior to start of sanitary landfilling. Section I is used for recreation. Section II will include administration and maintenance facilities, as well as containment area for storing dredged material cover. Section III is site of initial solid waste (SW) hill, with a second hill to be constructed in Section V, and the main hill in Sections II and IV. A second containment area will be required in Sections IV or V to provide cover for main hill in Sections II and V. The interior dike surrounding Section I provides an access route for hills in Sections III, IV, and V.



PHASE IV: COMPLETION OF SANITARY LANDFILL - To construct the third and final hill, the containment area in Section II must be removed. A new containment area is then constructed in Section IV and/or V, as dictated by area requirements and field conditions. After completion of hill #3, the containment area is removed; and recreation facilities and landscaping are completed, including construction of beach.

Figure 17. Four-phase construction sequence for hill construction using solid waste and dredged material

of Section I so it can be used at the earliest time.

71. As soon as Section I is filled and a crust capable of supporting men has formed, the area should be landscaped. Of great importance is the planting of trees and other vegetation. In addition to its value as a screen to the dredging and sanitary landfilling operations, vegetation will help dewater the dredged material. As shown in Figure 17, the recreation area in Section I can be developed while dredging continues and the other sections are filled.

Hill construction procedure

72. Construction of the solid waste hill (Section III) can begin when (a) the base has stabilized enough to support delivery vehicles and compaction equipment, (b) the groundwater table within the section is permanently below any solid waste disposal area, and (c) sufficient dried dredged material has been stockpiled for use as cover. When these preliminary requirements are met, the area method can be used to construct the hill (Figure 18). When the first hill is complete and Section V has been prepared, the second hill is constructed followed by the third. The hill construction sequence is shown in Figure 17.

73. Foundation preparation. Before a solid waste hill can be constructed, the dredged material land base must be capable of supporting the loads associated with the sanitary landfilling operation. This includes the ability to support vehicles and the incremental increase in the weight of the solid waste. The report of the Virginia Beach project stated that the foundation soils were capable of densifying at a rate greater than the slow-loading rate characteristic of sanitary landfilling. This must be evaluated on a site-by-site basis for the dredged material to be used.

74. Due to the high water content of dredged material placed in containment areas, the rate of load application due to hill construction must be carefully compared with the rate at which the dredged material will consolidate. The formation of excessive pore pressures must be prevented. If load is applied too quickly, a mud wave of dredged material may be caused; the displacement of dredged material, possible dike failure, and inundation of the solid waste are among the catastrophic

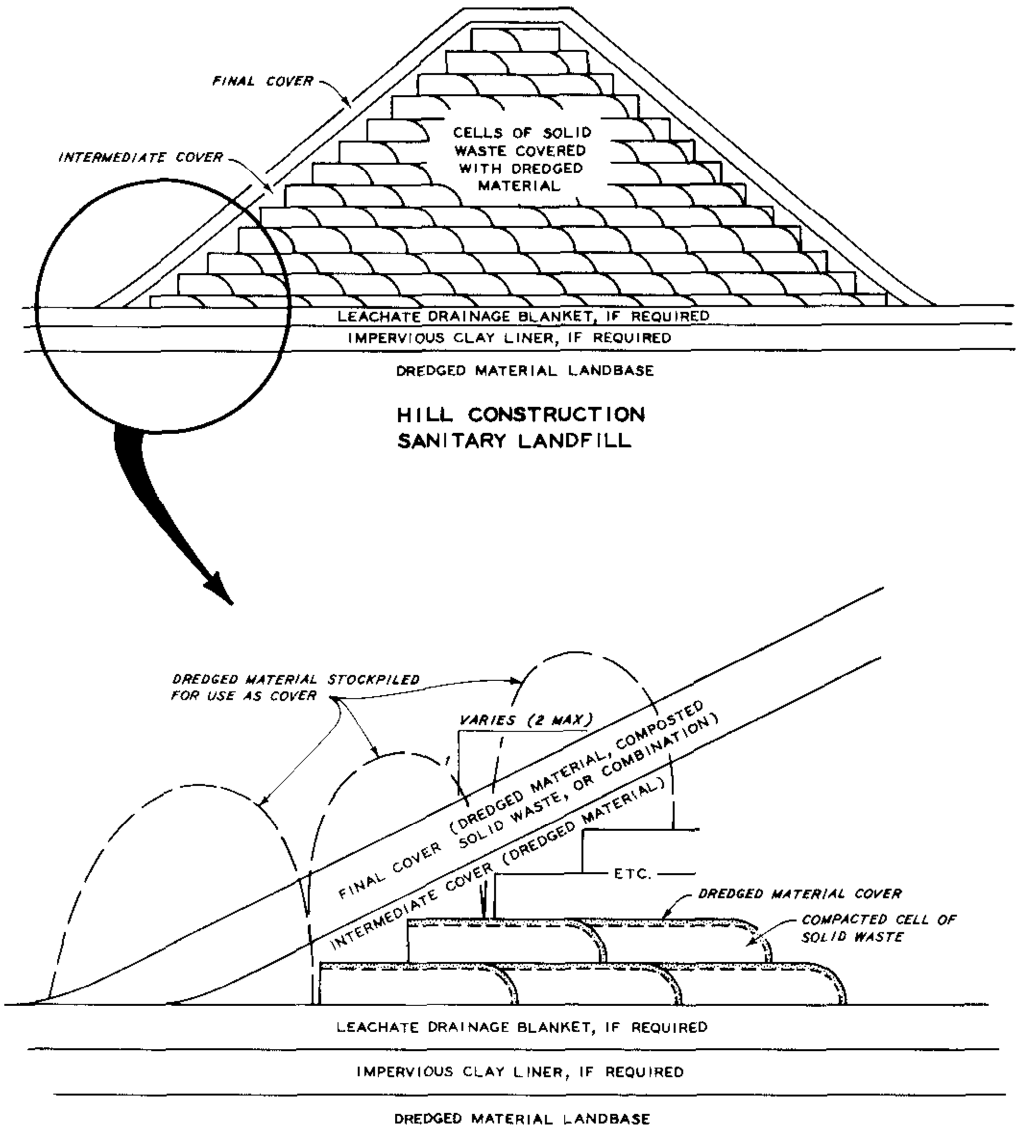


Figure 18. Solid waste hill construction details[19]

results possible. As long as drainage in the dredged material layer is provided and the rate of surface loading is carefully controlled, no difficulties should be encountered. An additional safety factor results if the surface of the dredged material is well above the water table and if the water table of the dredged material coincides with the external permanent water table.

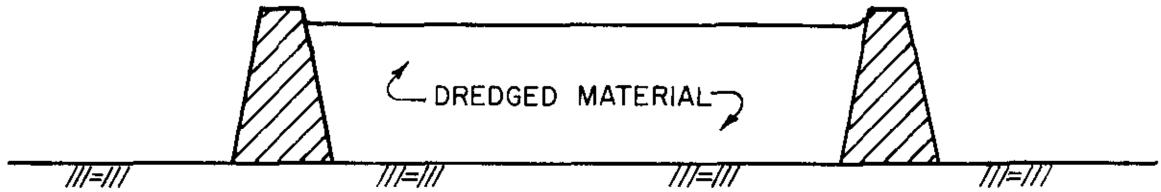
75. Additional preparation of the foundation may be required at some sites to control leachate. If the water table in the dredged

material is near the surface and any part of the foundation is fairly pervious, a liner of compacted clay dredged material may be required. If the production of leachate is considered to be a problem, whether a liner is constructed or not, a leachate drainage blanket of clean sand or gravel thick enough to collect and drain the leachate should be constructed prior to hill construction. The materials for both the clay layer and the drainage blanket may be available from Section II.

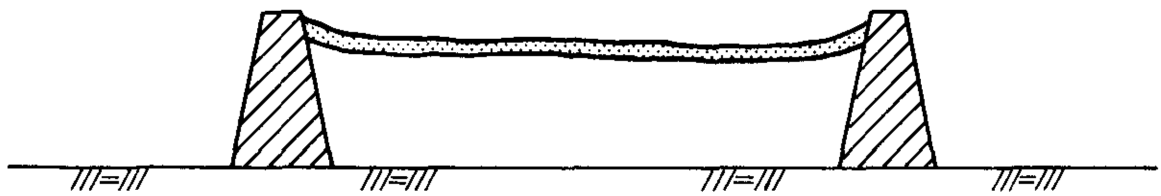
76. Cover material. Daily deposits of solid waste must be covered by dredged material near optimum moisture content. A containment area constructed in Section II is used to store and dry the dredged material to be used for cover. Drying the dredged material may be accomplished in a number of ways that are listed in Appendix B; the actual method will be site specific. For purposes of this report, however, the dredged material is assumed suitable for drying by the following crust management technique.

77. As a material dries in the containment area, a crust forms on the surface (Figure 19). As the crust forms, it is removed and stockpiled outside the containment area. The wet dredged material exposed by the crust removal is then allowed to dry, forming another crust. As layers of crust are formed, they are removed and stockpiled, until the containment area has been emptied. Research into the rate of crust formation is currently being conducted under the DMRP, and the information from this work will be useful in designing the containment area so that enough dredged material will be dried in time to allow uninterrupted solid waste disposal.

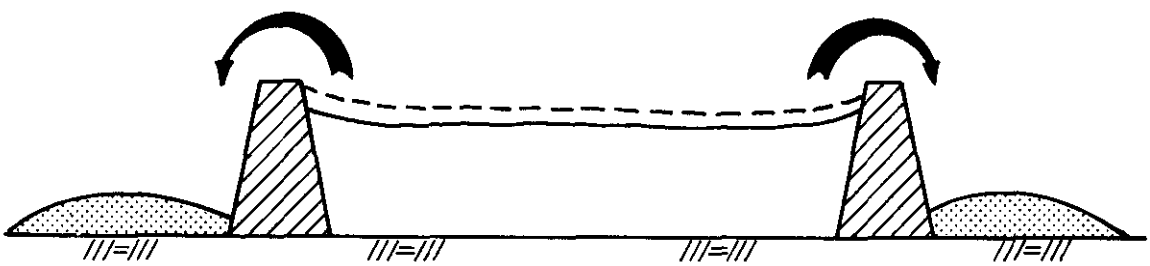
78. Construction procedure. The hill construction procedure for a project of this nature is similar to any other project using the area method but differs in some ways due to the characteristics of dredged material. In order to sustain an uninterrupted solid waste disposal operation, two things are especially important. First, there must always be a sufficient amount of dried dredged material to cover the solid waste; second, access to and from the solid waste hills must always be provided. Providing enough dredged material requires careful coordination of the dredging schedule, containment area design, and



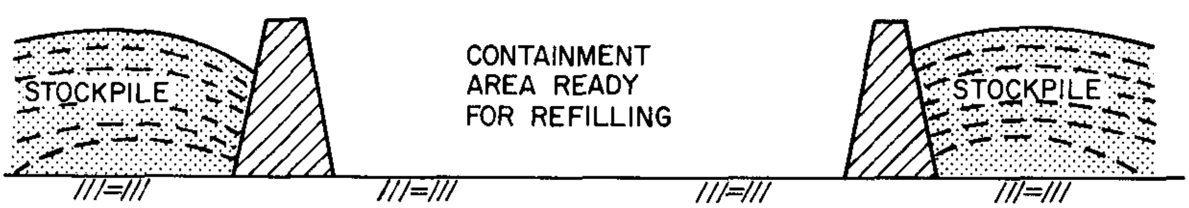
a. Filled containment area



b. Initial crust formation



c. Crust removed and stockpiled, new crust formation initiated



d. Stockpiled dredged material ready for use as cover

Figure 19. Crust formation managed to dry dredged material for use as cover[21]

dredged material drying schedule. A lack of cover may cause health problems and possible operation shutdown because the solid waste must be covered every day. Access to and from the solid waste hills is especially difficult on a dredged material land base because recently placed deposits may be too soft to support vehicular traffic. This restricts all traffic to travel on the dikes.

79. The locations of the two dredged material containment areas for storing and drying cover are shown in Figure 20. The area in Section II is used for cover for hills 1 and 2 and was located in Section II because that section will be stabilized before Section IV or V and will be the site of the last hill. Daily cover for the third hill will be stored in the containment area shown in Sections IV and V. This area will also be used to store the final cover. Access to the hills is provided by the interior dikes as shown in Figure 20. The interior dike separating Sections II and IV will require removal if differential settlement in hill 3 is anticipated. If settlement in the dike due to the

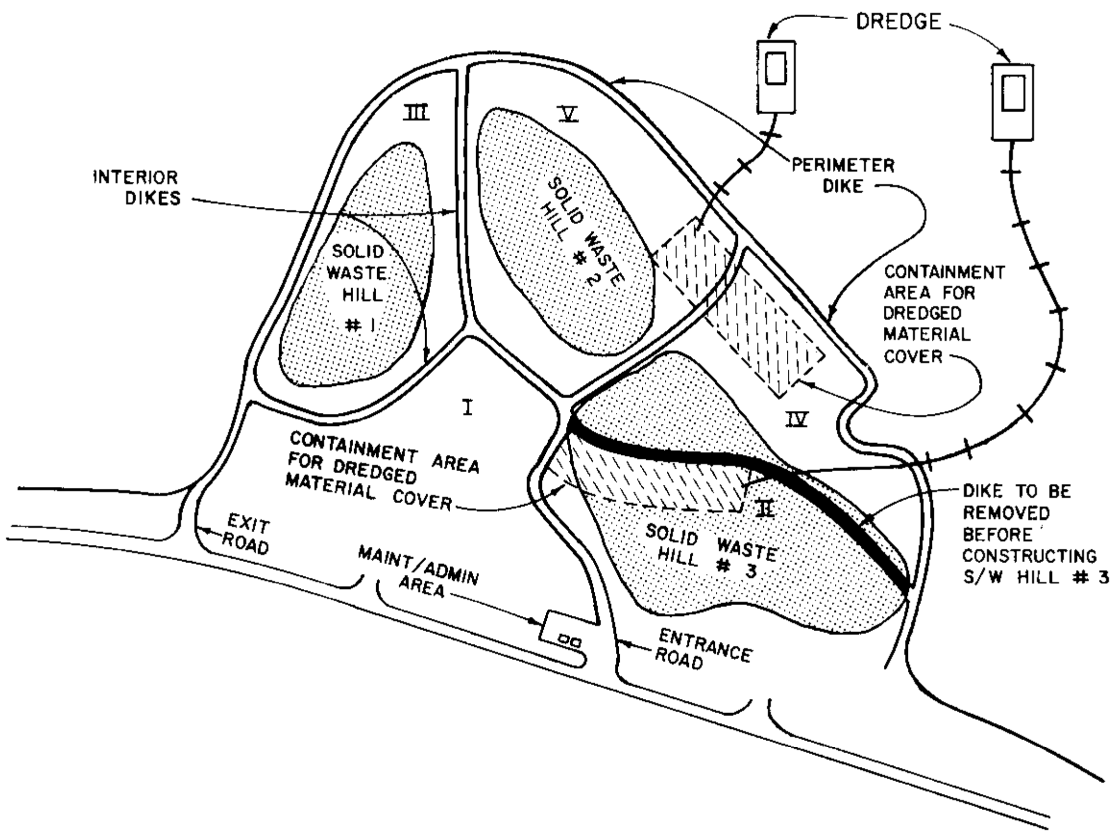


Figure 20. Operational aspects of solid waste hill construction

load caused by hill 3 is going to be substantially different from the settlement in the dredged material, then the dike must be removed and replaced with material similar to the dredged material.

80. Environmental considerations. Factors related to the environment must be considered, including leachate and gas control, aesthetics, and the effluent forced from the dredged material land base as it consolidates. If leachate is produced, it must be collected and treated. Collection can be accomplished by a drainage blanket as previously described, but treatment will be site-specific. After the solid waste disposal operation is complete, the empty containment area in Sections IV and V may be suitable for conversion to a leachate treatment facility. The control of gas from a solid waste hill is no problem as long as the gas is allowed to move laterally or upward, since it will vent to the atmosphere in these directions. The entire dredging and hill construction operation should be screened from the public by the use of trees and shrubs. If contaminants are included in the water squeezed from the dredged material as it consolidates, this water will require treatment. DMRP research is currently investigating the release of contaminants with dredged material effluent. Other environmental factors pertinent to any sanitary landfill are also to be considered.

81. Options. There are many variations of the project described above, but three are especially noteworthy. If composting becomes an established solid waste management technique in the U. S., then composting at a project of this type should be included. The technique should be included because composting of the organic solid waste would reduce the volume of the waste and extend the life of the site and because the compost could also be used as final cover, either by itself or mixed with dredged material as suggested in Part II. Another option that would extend site life would be the use of a modified trench method (as described previously in this part) to form the foundation for the solid waste hills. Finally, the entire project could be constructed as an island with access by bridge or causeway.

82. Benefits. If a project such as this could be successfully accomplished, benefits would be realized by the Corps of Engineers and

by the local community. The Corps would benefit by being provided with a containment area that might be near a dredging site, and the local community would benefit from use of the dredged material as cover and landbase and from the recreational facility creation at the completion of the project. Actual benefits will be site specific and will depend on factors including project size, distance to dredging site, cost of dredged material to community, etc. Due to the negative attitude of many toward dredged material and solid waste disposal, public opposition to a project of this nature is to be expected. Public acceptance may be hastened by showing that a tangible benefit (the recreation area) to the community will be produced as soon as possible. The recreation area can be landscaped with trees and shrubbery to screen both the ongoing dredging operation and the sanitary landfill hill construction from public view.

Slurry Injection

83. As a completed sanitary landfill ages, decomposition of solid waste results in the formation of void spaces in the cells. The decomposition may also result in internal fires due to spontaneous combustion of methane. Such fires cause even greater and more rapid void formation as the solid waste is burned. In a letter addressed to Green Associates and published in the report by Reikenis et al.,[11] the executive director of the Hackensack Meadowlands Development Commission suggested:

> ...the possible use of hydraulic fill as a landfill fire preventive technique. Pumping hydraulic fill into an existing inactive landfill site may serve the purpose of filling internal voids, which may at times become the origin of underground combustion.

84. In a subsequent discussion with EPA personnel,* the following concept of slurry injection was suggested. A pipe is inserted into an inactive sanitary landfill, penetrating to the bottom lift of solid

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* Personal communication, Norbert Schomaker, EPA National Environmental Research Center, Cincinnati, Ohio, 24 Feb 1976.

waste cells, and a slurry of dredged material and water is pumped through the pipe into the solid waste. The slurry is pumped at the highest solids content practical. As the voids are filled, the pipe is raised, filling the voids in the successive cells until all cells penetrated by the pipe have been filled. When one vertical column of cells has been filled, the pipe is completely withdrawn and reinserted to fill another column of cells; the procedure is repeated until all landfill voids have been filled with slurry.

85. Options for this concept include the location of the dredged material containment area, the method of delivery of slurry to the injection pipe, and the number of injection pipes used. Due to the intermittent demand for dredged material and the need for relatively low flows of slurry (as compared with the production rate of a dredge), a rehandling containment area is required between the dredge and the sanitary landfill. This containment area can be located near the dredging operation, with subsequent rehandling and transportation of dredged material to the sanitary landfill. Alternatively, the containment area may be located at a location mutually convenient to several inactive sanitary landfills and to the dredging operation.

86. Transportation of dredged material to the sanitary landfill from the containment area may be accomplished by means of a tank truck equipped with a pumpout system or by a small dredge such as the Mud Cat* operating in the containment area. Use of the tank truck requires only one injection pipe at a time, with the pipe diameter, pump capacity, etc., to be determined on a site-by-site basis. The use of a small dredge will require the use of several injection pipes to divide the flow. While some pressure may be required to break through thin walls of solid waste to ensure that the filling of all voids is accomplished, excessive pressure may threaten the structural integrity of the sanitary landfill. The use of a small dredge pumping to several injection pipes is illustrated in Figure 21.

87. Limited application of this concept is anticipated due to

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* Trade name, National Car Rental System, Inc.

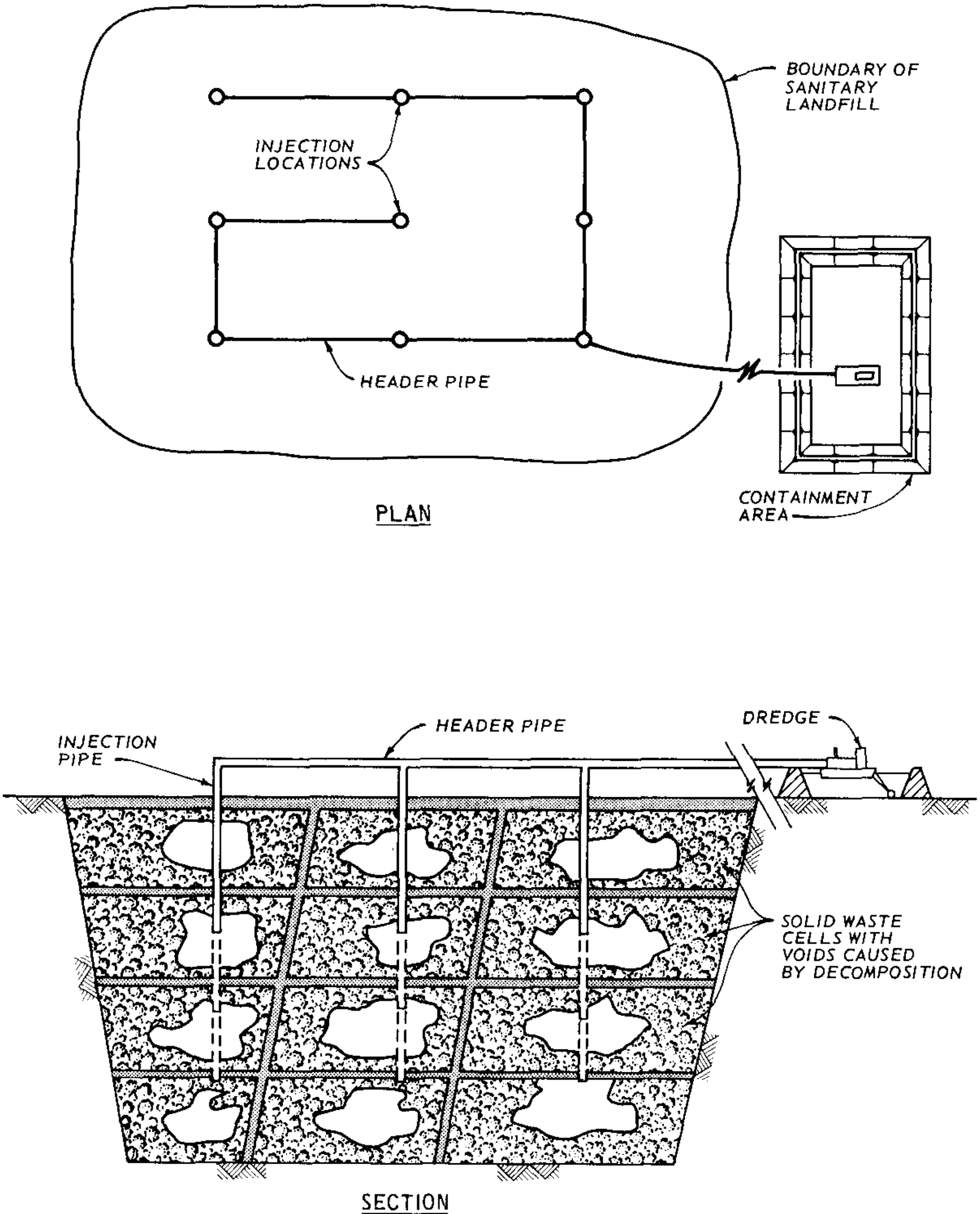

Figure 21. Injection of dredged material into the decomposition voids of an old sanitary landfill

several factors. The introduction of a large volume of water into a sanitary landfill will certainly cause the production of leachate, which must be collected and treated. In addition, insertion of a pipe into a solid waste cell does not necessarily mean that the pipe will be inserted into a void. Hydraulic pressure may force the slurry to punch through thin walls of solid waste, but this is not necessarily so. The relatively small volume of dredged material used in this manner is not much of an incentive for the Corps of Engineers to coordinate in such a venture, so the acquisition and transportation of dredged material from larger containment areas will probably be the responsibility of the user. Finally, the insertion of an injection pipe, the subsequent raising of the pipe, the pumping of the dredged material, etc., may prove overly expensive.

88. The benefits of such an operation may be worth the expense under some conditions, however. Smoke from underground fires in old sanitary landfills has caused traffic accidents by reducing visibility. The nuisance and health hazards presented by smoldering underground fires can be very troublesome, and prompt abatement is most desirable. The injection of water may extinguish the fire, but presents the same problems with leachate that the injection of dredged slurry would cause. In addition, water does nothing to fill the voids, which may cause subsidence problems. The injection of slurry would contribute some solid material to help fill the voids, and if equipment and dredged material are available, the operation may be economically feasible.

PART IV: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

89. Dredged material that has been dried to the point that it has a water content comparable to that of similar natural soil generally has the physical and engineering properties required to be suitable for several uses in a sanitary landfill. Construction of cover, liners, and gas barriers is technically feasible, based on a comparison of the properties of suitable natural soils with the properties of dewatered dredged material.

90. The use of dredged material in slurry or semisolid forms is not feasible in a conventional sanitary landfilling operation. However, the use of dredged material as a slurry injected into existing sanitary landfills to fill voids and also to control underground fires appears feasible but limited in application. The use of semisolid dredged material to cover entire lifts of shredded solid waste (which does not require daily cover in many cases) is feasible when trafficability in the area is not immediately necessary.

91. Since coarse-grained dredged material (sand and gravel) is free-draining and does not require dewatering, such material is ready for use as it exists in the containment area. This coarse-grained dredged material can be used to construct drainage blankets for collecting leachate and can be used to vent decomposition gases to the atmosphere.

92. The area method of sanitary landfilling is the most adaptable to the use of dredged material as cover, although the trench method is applicable when proper planning, design, construction, and operation are undertaken. In such cases a filled containment area could serve as a sanitary landfill.

93. No procedure for quantitatively evaluating the ability of a material to meet the functional requirements of the uses of dredged material cited herein has been established by the field of solid waste management although qualitative guidelines are available. These

guidelines are so nonspecific that nearly any type of dewatered dredged material could be used in some way at a sanitary landfill.

94. If composting becomes a more widely used solid waste management operation in the U. S., then dredged material may be used to cover compost landfills or as an admixture to improve the physical properties. Until such time, no compost-related uses are anticipated.

95. Careful planning and close coordination are required to ensure the success of any venture involving the use of dredged material in solid waste management. Such coordinated effort has resulted in benefits for both the solid waste managers and the Corps of Engineers in the Detroit and Philadelphia Districts.

Recommendations

96. Corps of Engineers Districts should make all practical efforts to dewater at least portions of the dredged material in containment areas and should make the dewatered material readily available to solid waste management authorities and other potential users.

97. The use of inactive dredged material containment areas as sanitary landfills should be considered by solid waste management authorities in order to find use for otherwise wasted land.

98. Field studies should be conducted for some of the uses for dredged material in solid waste management cited herein. Studies of the modified trench method described for using a filled containment area for a sanitary landfill and the use of semisolid dredged material to cover a lift of shredded solid waste should receive priority as they represent untested concepts for using significant quantities of dredged material.

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APPENDIX A: SOLID WASTE MANAGEMENT

1. The main text of this report points out the need for cooperation among agencies responsible for solid waste management and those responsible for dredged material disposal; effective cooperation will be facilitated when each agency is familiar with the operations of the other agencies. This appendix presents a brief discussion of current solid waste operations and processes to familiarize the reader with solid waste management.

2. Most solid waste is ultimately disposed on land in a landfill; the best land disposal operation currently used is sanitary landfilling, in which solid waste is covered with soil at the end of each day's operation. Other solid waste management techniques, such as composting and incineration, are also in use; but these are not ultimate disposal methods, since each results in an end product that must be disposed. Composting and sanitary landfilling, the two methods cited in the main text, are discussed in this appendix.

Composting

3. Composting is the biodegradation of the organic fraction of solid waste material; the end product is a humus-like substance that is used primarily for soil conditioning.[5*] There are five fundamental steps in composting: preparation, digestion, curing, finishing, and storage or disposal; each is described below.

Preparation

4. Preparation for composting may consist of several different operations including sorting/separation, shredding, addition of nitrogen, and water content adjustment. Sorting and separation are required to remove noncompostable items and items that could damage the shredding equipment. Material separated from the compost stream is further sorted,

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* Raised numbers refer to similarly numbered items in the References at the end of the main text.

with salvageable items recycled and other items transported to a sanitary landfill.

5. Shredding of refuse prior to composting produces several different beneficial results. Shredding increases the surface area of the solid waste, which makes it more susceptible to aerobic decomposition. The increased homogeneity of shredded waste makes it easier to handle, more attractive, and more responsive to moisture control. Shredded waste heats more uniformly, resists rainfall better, and is easier to aerate than unshredded solid waste. Shredding may involve the entire volume of shreddable solid waste or may be limited to the compostable portion. If noncompostables are to be landfilled, shredding may be an initial step in material recovery and landfilling, in which case all shreddable solid waste would be shredded prior to sorting. Otherwise, sorting should be accomplished before shredding so that only the compostable fraction would be shredded.

6. An important factor in composting is the carbon-nitrogen (C:N) ratio. This factor affects not only the rate of decomposition, but also the value of the compost as a soil conditioner. Research at the University of California[22] has shown that the decomposition rate of compost is optimal with a C:N ratio between 30 and 35. Generally the rate of decomposition is inversely proportional to the C:N ratio, and the decomposition rate will decrease considerably when the C:N ratio is greater than 40. Also, if compost is to be used to condition soil, the C:N ratio should not be greater than 20. If the C:N ratio is too large, the nitrogen in the soil could be drawn upon by the microorganisms in the compost, and this would cause a delay in the availability of nitrogen as a nutrient to support plant life. The adjustment of nitrogen content, if required, is often achieved by the addition of nitrogen-rich sludge from wastewater treatment plants.

7. The satisfactory range of water content is 40 to 60 percent by wet weight.[22] Moisture conditions drier than this range deprive microorganisms of water needed to maintain their metabolism; while too much water may reduce the amount of interstitial air available and give rise to anaerobic conditions. Generally speaking, above the minimum of

40 percent, increased water content requires increased aeration to prevent formation of anaerobic conditions. Moisture content may be increased by spraying water on material during turning or by using wastewater sludge in conjunction with nitrogen adjustment.

Digestion

8. Digestion or decomposition may occur under either aerobic or anaerobic conditions. Anaerobic decomposition may require as long as 6 to 8 months; windrowed aerobic decomposition requires only 4 to 6 weeks; and enclosed aerobic decomposition requires only a matter of days. Due to the long time period required for anaerobic decomposition, most compost plants operate under aerobic conditions. Aerobic plants are either windrow operations or mechanical operations.

9. In windrowed composting, shredded and moistened solid waste with a satisfactory C:N ratio is placed outdoors in windrows. The windrows are turned once or twice every week to ensure satisfactory aeration and mixing. Turning may be accomplished by machinery that picks up the material and places it back on the ground. Other special equipment straddles the windrow and uses a drum with teeth to turn the solid waste in place.

10. Windrow composting has several disadvantages that limit its application. Moisture control is difficult because outdoor operations are subject to rainfall. Due to the lengthy digestion period (4 to 6 weeks), a storage area sufficient to accommodate the solid waste for several months is required. For example, the storage of waste from a city of 20,000 would require 55-60 acres of land.[5] Control of odors emanating from the digesting compost is difficult due to the outdoor location, and the windrows may be attractive to vectors, especially flies and birds. Due to these limitations, windrow composting is well suited only to small cities in warm, dry climates; as a result, most composting plants in the U. S. have mechanical digesters.

11. Mechanical composters offer several advantages over windrow composting because the decomposition takes place in an enclosed, controlled-environment digester. In an enclosed digester, forced or natural air maintains the oxygen level required by aerobic

microorganisms decomposing the solid waste. Turning is accomplished intermittently by special equipment or constantly by mixers or rotating digesters. Mechanical digestion takes only 3 to 10 days.

Curing

12. The process of curing is the same as digestion but proceeds at a much slower rate. After digestion is finished, the compost is moved to an enclosed curing shed for about 2 weeks, during which time the product is allowed to stabilize.

Finishing

13. Finishing is an optional step in a composting operation. If compost is to be landfilled or used in other bulk applications, finishing is not required. However, if appearance is important or if miscellaneous debris (bits of plastic, glass, etc.) are objectionable, then finishing is required. Finishing operations include grinding and screening to remove debris and to provide a uniform appearance. Adjustment of water content may also be required to ensure that the compost does not include more than 30 percent water by wet weight.

Storage

14. Compost has not met with much success in the U. S., due mainly to the lack of markets for the product. When a market does exist, it is generally seasonal with peak demands in the spring and fall. Due to the seasonal nature of the market, storage should be provided for at least 6 months production. For a plant processing 300 tons per day, 13 acres are required for storage. If curing is to be accomplished in the storage area, the shallower windrows required make it necessary to provide a larger area.

Sanitary Landfilling

15. Approximately 90 percent of the solid waste generated in the U. S. is ultimately disposed on land. This includes incinerator residue, composted solid waste, and wastewater treatment plant sludge. A recent survey revealed that there are more then 18,500 known land disposal sites in the U. S. (Table A1).[8] Land disposal sites have historically

Table A1

Survey of U. S. Disposal Practices*

(1) Location	(2) Number of Sites Presently Permitted or Otherwise Recognized as in Compliance with State Regulations	(3) Number of Authorized Landfills	(4) Number of Known Land Disposal Sites	(5) Number of Landfills Using Shredding	(6) Are Sites Which do Shredding Allowed to Landfill Without Daily Cover?	(7) Number of Sites Using Baling Before Landfilling	(8) Number of Sites with Impermeable Linings	(9) Number of Sites with Leachate Treatment Facilities
Region 1								
Connecticut	60	144	144	1	No	0	0	0
Maine	0	0	367	0	Yes	0	0	0
Massachusetts	96	75	324	1	No	1	0	0
New Hampshire	42	138	180	0	Would consider	0	0	0
Rhode Island	7	0	38	0	No	0	0	0
Vermont	20	55	95	0	No	0	1	0
Region 2								
Delaware	39	0	150*	1	No	1	0	1
New Jersey	138	138	307	0	Would consider	0	1	1
New York	424	376+	800+	2	Would consider	0	3	0
Region 3								
Maryland	39	67	91	0	Yes	0	0	2
Pennsylvania	129	0	379	0	Would consider	0	6	6
Virginia	173	173	188	0	Yes	0	1	1
West Virginia	42	24	300+	0	Yes	0	0	9
Region 4								
Alabama	111	23	143	0	No	0	0	1
Florida	35	179	500	1	Yes	0	0	6
Georgia	150	125	625	2	Yes	2	0	0
Kentucky	147	Unknown	147	0	No	0	0	4
Mississippi	54	0	274	0	No	0	0	0
North Carolina	156	Unknown	162	1	Would consider	0	0	0
South Carolina	176	100	276	3	Yes	0	0	0
Tennessee	102	10	250	0	No	2	0	2
Region 5								
Illinois	225	0	404	0	Yes	0	1	0
Indiana	110	110	151	0	No	0	0	0
Michigan	214	165	888	0	Would consider	0	3	3
Ohio	260	10	290	1	Yes	0	0	2
Minnesota	111	20	600	0	No	0	2	1
Wisconsin	1200	Unknown	1,314	2	Yes	0	0	2
Region 6								
Arkansas	47	Unknown	450+	0	Would consider	0	0	1
Louisiana	61	0	387	0	Yes	0	1	0
New Mexico	50	400	1,000	0	Yes	0	0	0
Texas	236	110	1,525*	3	Yes	1	2	12
Oklahoma	111	243	507	0	No	0	0	0
Region 7								
Iowa	No regulation	36	500	0	Would consider	0	0	0
Kansas	40	120	300	0	Yes	0	0	0
Missouri	48	88	390	0	Would consider	0	0	3
Nebraska	53	70	400	0	No	0	0	0
Region 8								
Colorado	125	255	255+	2	Yes	0	0	0
Montana	70	Unknown	514	1	Yes	0	0	0
Utah	3	4	272	0	No	0	0	0
Wyoming	Does not apply	Does not apply	80+	0	No	0	Unknown	0
North Dakota	Does not apply	Does not apply	412	0	Yes	0	0	0
South Dakota	16	16-	369	0	Yes	0	0	0
Region 9								
Arizona	70	0	160	0	No	0	0	0
California	107	195	441	0	Would consider	0	0	0
Hawaii	0	24	42*	0	No	0	0	0
Nevada	17	103	120	0	No	0	0	0
Region 10								
Alaska	42	0	200	0	Yes	0	0	1
Idaho	30	20	190	0	No	0	0	0
Oregon	180	133	241	0	Would consider	0	0	0
Washington	30	43	397	2	No	0	0	3
Grand Totals	5596	3792	18,539	23		7	21	61

Note: Column 2: Where states did not report any numbers, the sanitary landfill permitting program had not been established by the date of the survey.

Column 3: This question was interpreted to mean those sites which, because of the service performed, should be in compliance with state regulations. It was also used to include modified sanitary landfills, a classification which could not be reported in column 1. These sites do not include the permitted fills identified in column 1.

Column 4: This question includes all sites the state wished to report as a total; including dumps, sanitary landfills, and other land disposal classifications. Please note where this number was not provided by the state's representative, the WASTE AGE editors have provided an estimate, as noted by asterisk.

Column 6: This question referred specifically to the use of shredding equipment with respect to landfilling, not waste control facilities in general.

Column 8: The responses include artificial lining, asphalt, concrete, rubber, plastic, etc., as opposed to recompacted on-site soils.

Column 9: The interviewers tried to limit "treatment facilities" to those having actual process equipment. Some respondees may have included lagoons and temporary basins.

* Reprinted with permission from Three Sons Publishing Co. from "An Overview of the Land Disposal Problem."[8]

been open dumps where unprocessed solid waste was placed on land and allowed to decompose. Burning was often practiced to reduce the volume of the refuse and thereby extend the life of the dump. Today many states have banned open dumping and burning because of the attendant problems of health and environmental pollution and now dispose of solid waste in sanitary landfills.

16. Sanitary landfilling is an engineered method for the land disposal of solid waste. In a sanitary landfill operation, solid waste is spread on the ground and compacted to the maximum density practical. At the end of each working day, all solid waste delivered to the site during the day is covered with compacted soil. This constitutes a solid waste cell. A sanitary landfill consists of one or more lifts of solid waste cells. If two or more lifts are placed, each lift is covered by an intermediate cover. All completed sanitary landfills are covered with a thick final layer of soil. Figure A1 shows the cross section of a two-lift sanitary landfill.

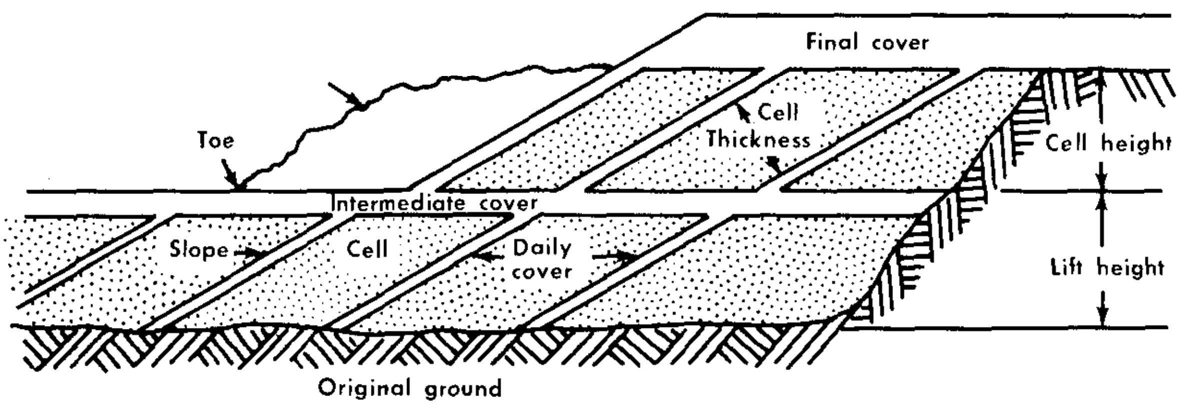


Figure A1. Cell construction[3]

17. While all sanitary landfill operations employ cell construction, there are different operational procedures. Variation of each operation is also possible by preceding cell construction with shredding or baling. Sanitary landfills also differ in the way they control the products of solid waste decomposition. The three basic operational procedures are described below, followed by explanations of the sanitary landfilling of baled or shredded solid waste. The section is completed with a discussion of the control of decomposition products.

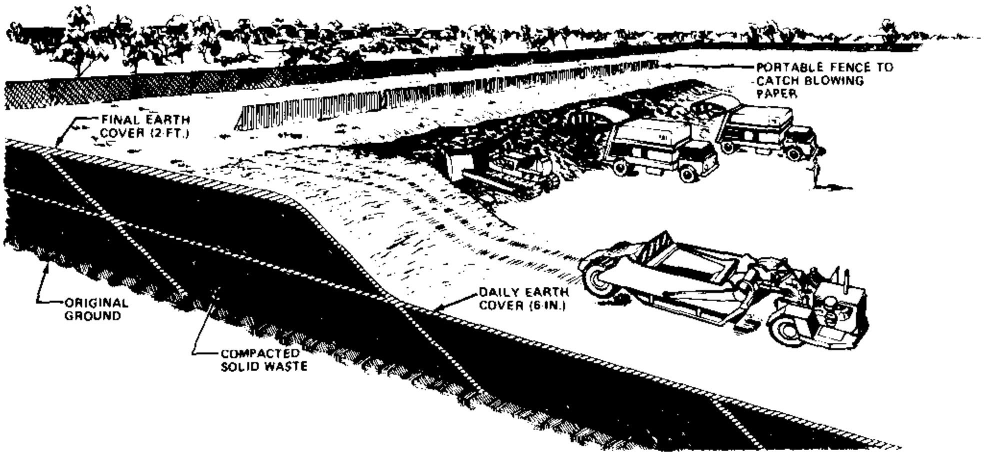
Operational procedures

18. The three basic types of operations used in sanitary landfilling are the area, trench, and ramp methods, Figure A2. The trench and ramp methods are used when sufficient cover material can be excavated at the site; the area method is used when borrow material must be imported for use as cover.

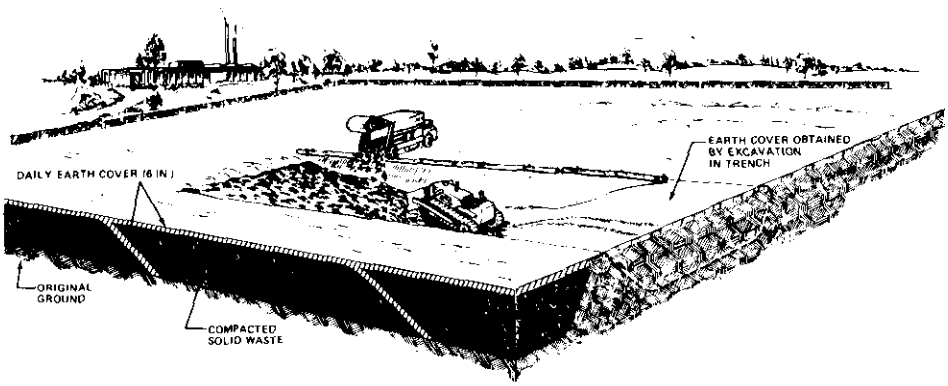
19. Area method. In the area method, solid waste is spread on the ground in thin layers and compacted. EPA suggests 10 ft as the maximum thickness for a layer of solid waste.[3] Soil is imported to the sanitary landfill and used to cover the compacted solid waste. The area method is used when the terrain is rough and irregular, where the groundwater table is at or near the surface, or where the native soil is not suitable for use as cover.

20. Trench method. The first step in the trench method is to excavate a long narrow trench to the maximum depth planned for the sanitary landfill. The soil excavated from the trench is stockpiled at a convenient nearby location. Solid waste is placed in the trench and compacted daily. Solid waste deposits are covered daily with the stockpiled soil to form a cell. Each lift is in turn covered by a thicker intermediate layer. After one trench is filled, another is excavated; this process is repeated until the site is completed. If there is an excess of soil after the trenches are filled, the site may be converted to the area method. The trench method is most suitable for sites where the terrain is fairly regular, sufficient cover soil is available, and the water table is fairly far below the surface.

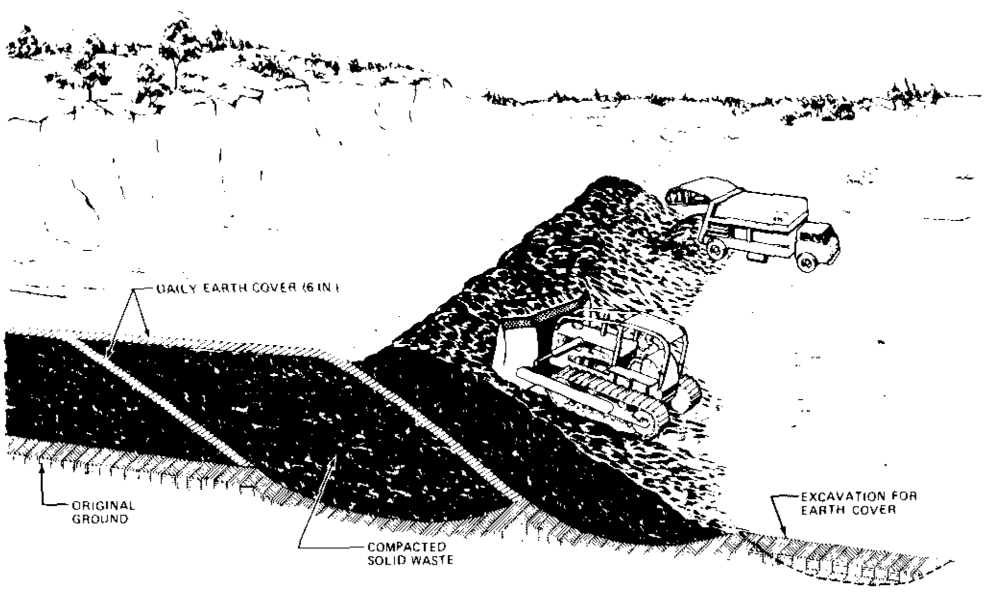
21. Ramp method. The ramp method combines features of both the area and the trench methods. As in the case of the trench method, material is excavated and stockpiled. As seen in Figure A2, however, the excavation is relatively shallow. Refuse is deposited against an existing earth slope, compacted, and covered with stockpiled soil. This process is repeated at the newly created slope of the cell. In this way the slope progresses across the site until the site is covered by a lift of solid waste. This is similar to the area method because most of the



a. Area method



b. Trench method



c. Ramp method

Figure A2. Basic types of sanitary landfill operations[3] solid waste is placed above grade. This method is suited to sites that allow only a shallow excavation.

22. Combination of methods. The area, ramp, and trench methods may be practiced in combination. For example, part of a site may have good cover soil while the remainder of the site does not. In this case the trench method would be used to the maximum extent possible with cover soil hauled in to complete the operation using the area method. Another variation involves using the trench method until the trenches are filled. Then the area method is employed to create a hill using excess stockpiled cover material and/or imported cover material.

Sanitary landfilling of baled solid waste

23. The use of baling as a preliminary step to a sanitary landfill offers several advantages over the standard process of on-site compaction. Bales of highly compacted solid waste do not require on-site compaction; the bales are simply stacked in a tight configuration and covered. Baling can lead to more efficient utilization of land. Since the density of baled solid waste is between 1600 and 1900 lb/cu yd, as compared with about 1000 lb/cu yd for solid waste compacted at the site, 60 to 90 percent more solid waste could be disposed at a site.[23]

Sanitary landfilling of shredded solid waste

24. The shredding of solid waste prior to sanitary landfilling can significantly increase the capacity of a site. Shredding increases the homogeneity and reduces the void spaces of solid waste, thus producing a higher in-place density after compaction. In addition, under some conditions shredded waste landfills do not require daily cover. Rats and other rodents are unable to obtain adequate supplies of food from shredded waste; fly larvae (maggots) are killed during the shredding process; and shredded solid waste is trafficable and not subject to blowing. Table A1 shows that there are 23 landfills using shredding located throughout the U. S., and that 15 of these sites do not require daily cover. Table A2 shows a comparison of the sanitary landfilling of unprocessed, baled, and shredded solid waste.

Table A2

Comparison of Sanitary Landfilling of Unprocessed, Baled, and Shredded Solid Waste[6]

Alternatives	Potential Advantages	Potential Disadvantages	Conditions Which Favor Alternative
Sanitary landfilling of unprocessed solid waste	Simple, easy to manage Initial investment and operating costs are low Can be put into operation in short period of time May be used to reclaim land Can receive most types of solid waste, eliminating the necessity for separation of wastes	Proper sanitary landfill standards must be observed or the operation may degenerate into an open dump Difficult to locate new sites because of citizen opposition Leachate may create water pollution Production of methane gas can constitute a fire or explosion hazard Obtaining adequate cover material may be difficult Process excludes resource conservation	Adequate land, close to source of waste, is available at reasonable price
Sanitary landfilling of baled solid wastes	Extends life of landfill (double that of unprocessed wastes) Lowers operating costs at the disposal site Reduces hauling costs where distant sites are used Permits immediate use of landfill site for other purpose upon completion (minimal settling) May reduce chance of water pollution from leachate		Long hauls needed to reach landfill sites Shortage of landfill sites require maximum utilization of available land Use of site is desired immediately after completion
Sanitary landfilling of shredded solid waste	Does not require daily cover under some conditions More easily placed and compacted Extends life of landfill Initial investment and operating costs are relatively low Vehicles do not become mired in waste in inclement weather Reduces problems with vectors Does not support combustion or lead to blowing litter Shredding at landfills may be first step in implementing a resource recovery system	Jamming and bridging of the feeding equipment can reduce throughput of the mill High level of component wear, especially on hammer Danger to employees from flying objects, explosions within the mills, and noise Leachate may create water pollution	Cover material is difficult to obtain Shortage of landfill sites requires maximum utilization of available land

Control of decomposition products

25. The decomposition of the solid waste placed in a sanitary landfill results in the generation of heat, gases, and leachate. Generally, both aerobic and anaerobic decomposition will occur in the upper layers of a sanitary landfill; anaerobic decomposition will proceed very slowly in deep layers. Heat is generated fairly rapidly, especially under aerobic conditions, raising the ambient temperature. This rise in temperature accelerates the rate of both aerobic and anaerobic decomposition, increasing the production of decomposition gases and leachate.

26. Gas generation and control. The decomposition of solid waste results in the production of gases. Aerobic decomposition will produce carbon dioxide until the supply of oxygen is depleted. Since carbon dioxide is heavier than air, it accumulates in the lowest levels of the landfill, but some carbon dioxide may be dissolved in water to form carbonic acid. High concentrations of carbonic acid dissolved in water can lead to groundwater contamination because many minerals are soluble in its presence. After the depletion of oxygen, the air entrapped within the sanitary landfill consists almost entirely of nitrogen, which may combine with hydrogen to form ammonia and present an oder problem.

27. Anaerobic decomposition results in the production of methane, hydrogen sulfide, and small amounts of other gases, such as ethylene and carbon monoxide. Methane may be a problem because it is explosive when mixed with air in concentrations between 5 and 15 percent. Methane vented to the atmosphere presents no problem, but lateral migration and venting into the basements of buildings poses a safety hazard. Methane is only slightly soluble in water and poses no threat to groundwater quality. The production of hydrogen sulfide is small compared with that of methane, but hydrogen sulfide may cause a severe odor problem and is toxic even in low concentrations.

28. When a sanitary landfill is covered by a layer of impermeable soil, gases may move laterally in an attempt to vent to the atmosphere. To prevent gas migration, proper ventilation must be ensured. Gas vents may be gravel layers placed between cells, as shown in Figure 7 of the main text; gravel interceptor trenches at the perimeter of the landfill

(Figure 8); or horizontal gravel blankets with perforated collector pipes vented through the impermeable layer to the atmosphere (Figure 9).

29. Since gas is able to move more easily through dry, permeable soils than through impermeable soil saturated with water, an effective gas barrier consisting of a perimeter wall of wet clay may be used to confine the gases within the sanitary landfill. Such a barrier may be used in combination with a ventilation system. An impermeable liner used to control leachate may also be a barrier to gas movement, provided the liner completely surrounds the landfill and extends to the surface. Figures 5 and 6 of the main text show gas-barrier walls and liners, respectively.

30. Leachate production and control. When most or all of a sanitary landfill becomes saturated with water, the addition of water will produce seepage from the landfill, with water emerging at the surface and/or into the surrounding soil. Water seeping or percolating through a sanitary landfill leaches dissolved and suspended material from the solid waste and carries this material out of the landfill. This contaminated water is termed leachate and is similar to strong industrial wastewater. To avoid the contamination of surface water and groundwater, the production of leachate must be prevented. Alternatively, the leachate may be prevented from entering groundwater and surface water.

31. The prevention of leachate is a matter of keeping water from entering the landfill. Water may be furnished to the landfill by three means: infiltration of rainfall, groundwater capillarity or seepage, and moisture in the solid waste. Elimination of the moisture in solid waste is impractical, so rainfall and groundwater must not be allowed to enter the landfill if leachate is to be prevented.

32. The infiltration of surface water can be minimized by an impermeable soil layer placed over the solid waste. The amount of water actually entering the cover can be kept low by ensuring surface drainage. Water entering the soil cover can be removed by vegetation.

33. The prevention of the entrance of goundwater into a sanitary landfill may require the construction of an impermeable liner prior to operating the sanitary landfill. The EPA has reported on an

investigation to assess liner materials for sanitary landfills.[9] The report concludes that asphalt, polymeric membranes, treated soil, and natural soil appear effective for lining sanitary landfills; but that long-term information is required for a complete assessment.

34. The sealing of sanitary landfills may have some serious disadvantages, however. Water is required by microorganisms to decompose the solid waste; if there is a water deficiency, the rate of decomposition and, therefore, stability will be retarded. In very wet climates the prevention of leachate may be impractical due to the requirement for large amounts of soil with which to construct thick liners and cover layers.

35. In most cases where leachate production may endanger water supplies, collection of the leachate may be advantageous. Leachate collection is accomplished by a drainage layer at the base of the sanitary landfill. The drainage layer is placed on top of a natural impervious layer or on a liner as shown in Figure 10 of the main text. The drainage layer generally consists of a blanket of sand or gravel with or without collector pipes. In any case, the leachate is drained to a sump where it can be collected.

36. Traditionally, collected leachate has been transported to a wastewater treatment plant for treatment. An innovation in solid waste disposal is the recirculation of leachate. In this method, the collected leachate is reintroduced at the surface of the landfill and allowed to percolate through the solid waste repeatedly until no further leaching occurs. The leachate is then transported for treatment. The results of leachate circulation are an increase in decomposition rate and a reduction in the volume of leachate to be treated. Research into leachate recirculation has been published by EPA.[24] The distribution system for a sanitary landfill with leachate recirculation is shown in Figure A3.

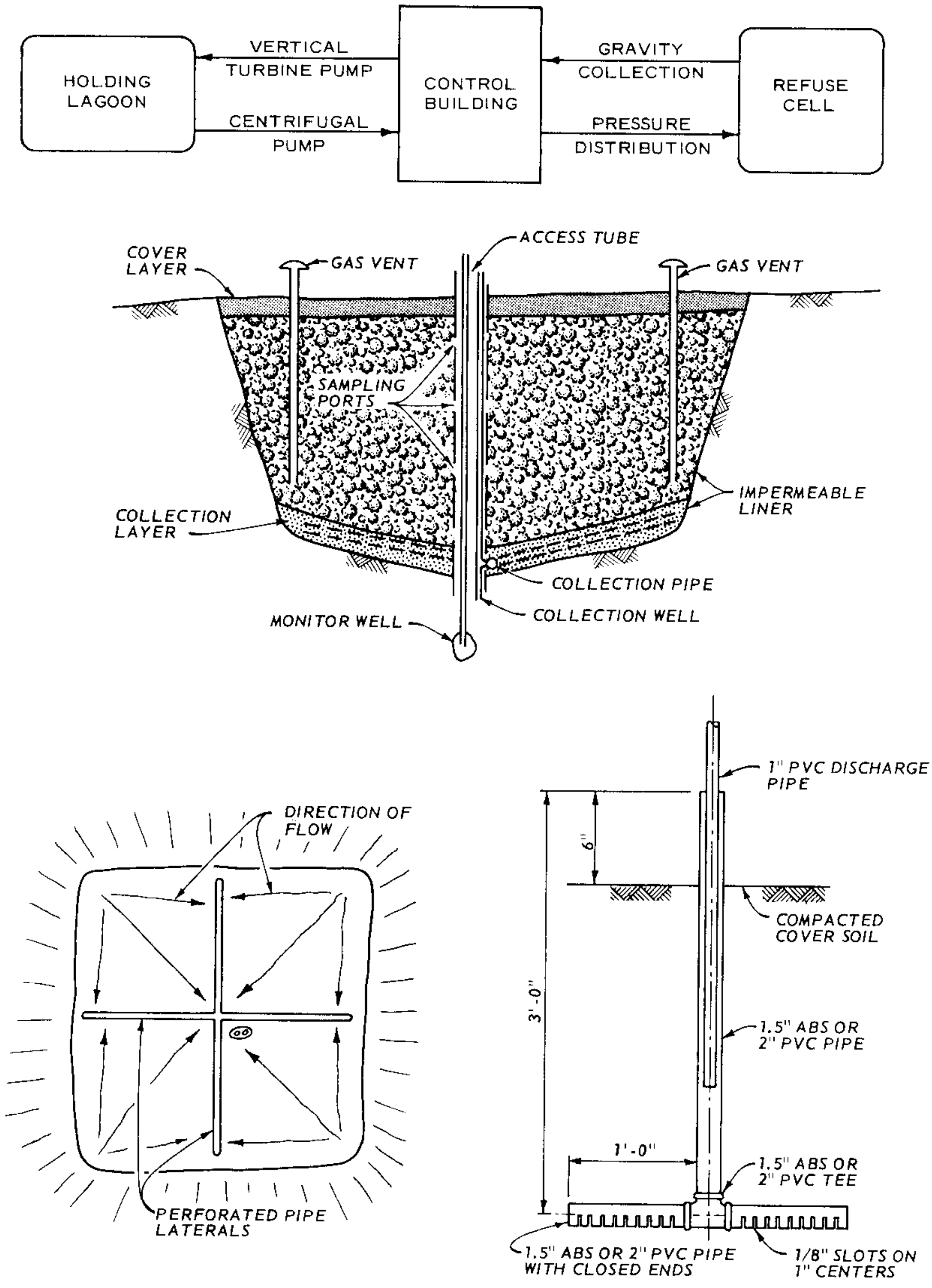


Figure A3. Distribution system in a leachate recirculation landfill (from Handbook of Solid Waste Disposal: Materials and Energy Recovery by Pavoni, Heer, and Hagerty, 1975 Litton Educational Publishing, Inc. Reprinted by permission of Van Nostrand Reinhold Company)[5,24]

APPENDIX B: DREDGED MATERIAL DISPOSAL

1. Maintenance of the navigable waterways of the U. S. involves dredging and disposing of sediment. The purpose of this appendix is to provide a convenient reference to the fundamentals of dredged material disposal and to show the forms dredged material takes during each phase from dredging to ultimate use. Hydraulic dredging, dredged material containment, and dredged material dewatering are discussed.

Dredging

2. Dredges currently in use in the U. S. can be classified as hydraulic, mechanical, or pneumatic. Most Corps of Engineers (CE) maintenance dredging is currently performed using hydraulic dredges;[25*] the quantity of material dredged by mechanical or pneumatic systems is insignificant for purposes of this study. Therefore, unless specifically stated otherwise, only hydraulic dredging is considered.

3. Hydraulic dredges (Figure B1) are of two types: pipeline and hopper dredges. Pipeline and hopper dredges are similar in that both types excavate sediment from a channel bottom by means of a suction pipeline. This hydraulic excavation causes the sediment to be mixed with large quantities of water forming a slurry of between 10 and 20 percent solids by weight. With either type dredge, the dredged material is transported to a containment area as slurry.

4. Pipeline and hopper dredges differ in the way they advance during the excavation and in the way they transport the dredged slurry to the containment area. Pipeline dredges advance very slowly using spuds to move forward. The sediment is sucked up through the pipe and pumped through a floating pipeline to the containment area. Hopper dredges are self-propelled. Sediment is sucked up in the pipe and stored in hoppers aboard the dredge. When the hoppers are full, the dredge must be

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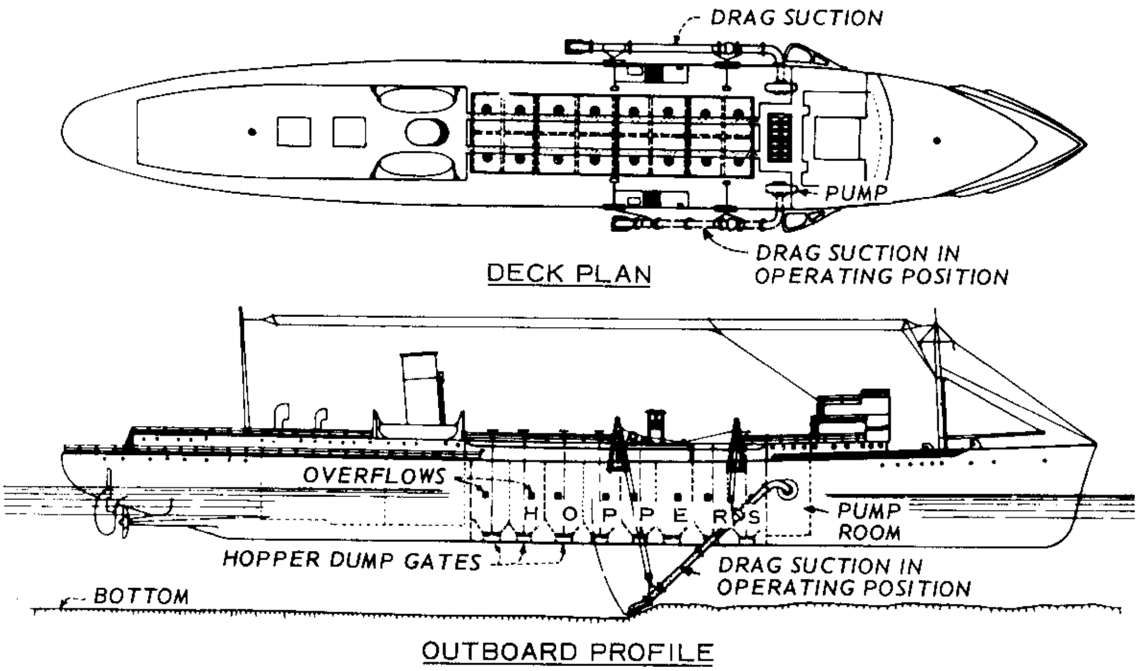
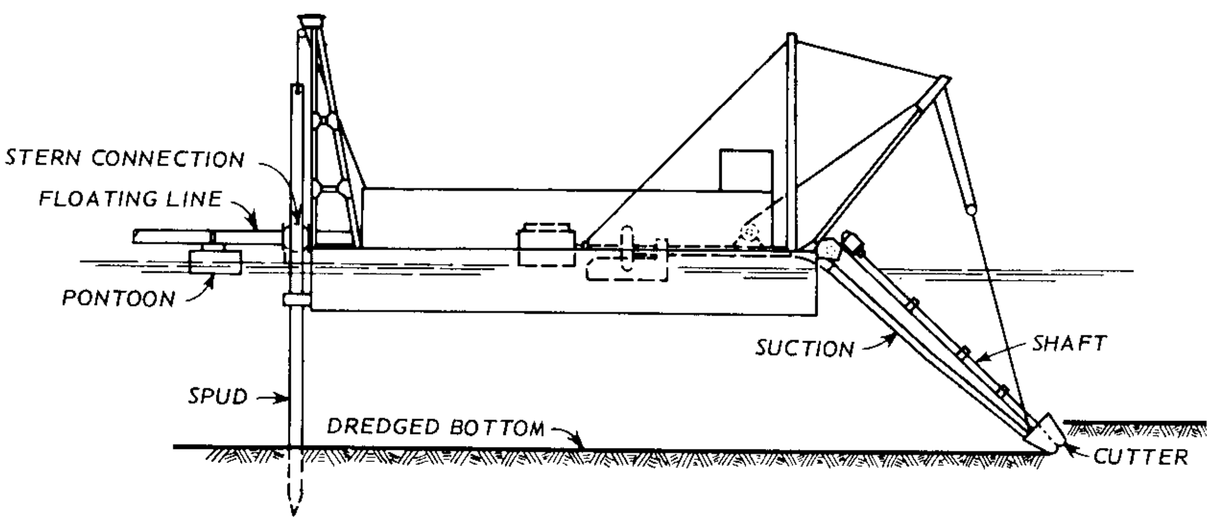
* Raised numbers refer to similarly numbered items in the References at the end of the main text.



TYPICAL HOPPER DREDGE



TYPICAL PIPELINE DREDGE

Figure B1. Hydraulic dredges[26] (Reprinted by permission from Hydraulic Dredging, John Huston, 1970 Cornell Maritime Press, Inc.)

emptied, either by pumpout or by bottom dumping. Generally, hopper dredges travel to the containment area to discharge a load of dredged material. Sometimes, however, the material is pumped directly into a barge, eliminating the nonproductive time spent by the hopper dredge traveling between the dredging site and the containment area. Table B1 summarizes hydraulic dredging; detailed information on dredges and dredging practices is give in Huston's Hydraulic Dredging.[26]

Containment

5. Approximately 67.1 million cu yd or 22.5 percent of the material dredged annually during CE maintenance operations is placed in containment areas.[26] Earth dikes, bulkhead structures, and natural terrain are used singly or in combination to form areas into which dredged slurry is pumped. There are several functions served by a containment area, two of which are pertinent to this study. A containment area should act as a settling basin in which some of the transport water is separated from the dredged material solids and removed from the area; the containment area should retain the settled solids.

6. During a typical confined disposal operation, hydraulically transported dredged slurry is placed into a containment area. As the slurry travels from the discharge pipe to the outlet structure, sedimentation occurs; and the dredged material segregates by particle size. Large and heavy particles, such as rock, gravel, and clay chunks, are deposited in a mound near the discharge pipe. Sand is carried slightly further; fine-grained material remains in suspension for a longer time and is deposited further from the discharge pipe.

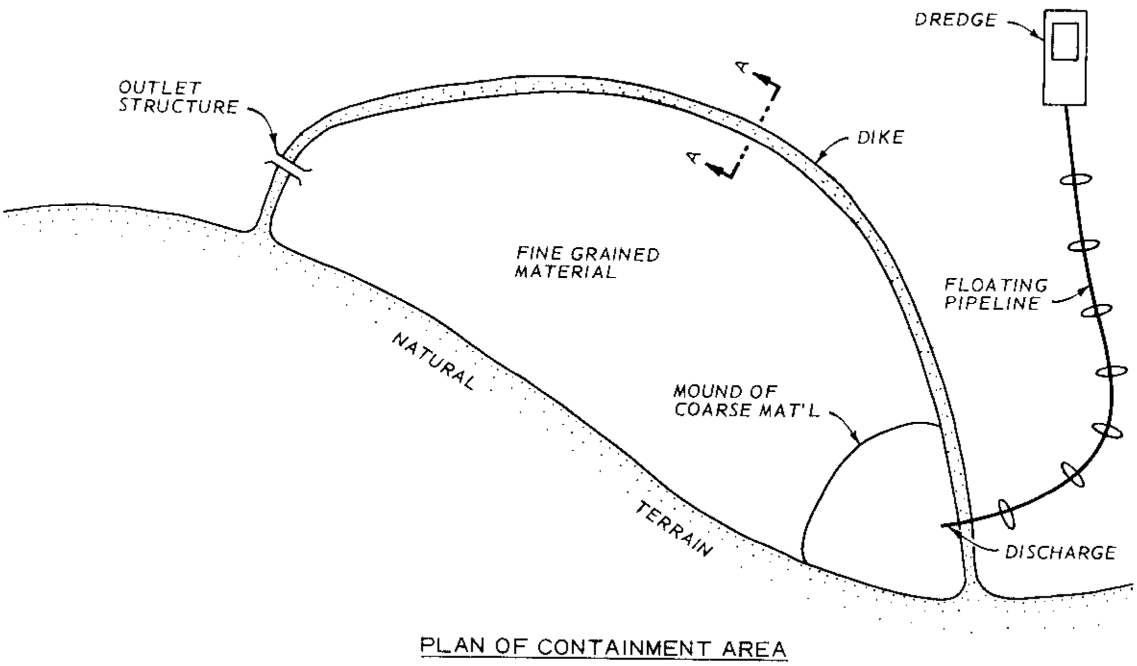
7. The coarse and sandy portions deposited near the discharge pipe are generally free draining and exist at relatively low water contents if drainage is provided. Silt and clay, however, settle from suspension very slowly and form deposits of material with low density and high water content; they may remain in this state for long periods of time, depending on drainage conditions, deposit thickness, vegetation, climate, etc. Figure B2 shows the pertinent features of a diked containment area.

8. After ponded water has been decanted, desiccation of the

Table B1

Dredging and Containment Operations

Dredging Method	Principal Application	Characteristics of Dredged Material at Time of Placement in Containment Area	Methods of Placing Dredged Material in Containment Area
Pipeline	Used universally except in areas of heavy navigation, e.g. harbors	Discrete silt, sand, and rock particles, discrete or agglomerated clay particles, shell and other miscellaneous fragments, in various combinations generally in slurry of 20% solids and 80% water by weight	Continuous operation floating pipeline discharging directly into containment area
Hopper	Used principally in areas where floating pipelines would interfere with navigation	Same as pipeline	Dredged material stored in hoppers may be: A. Bottom dumped into rehandling basin B. Pumped directly into containment area through pipeline C. Pumped directly into barges for transportation to containment area



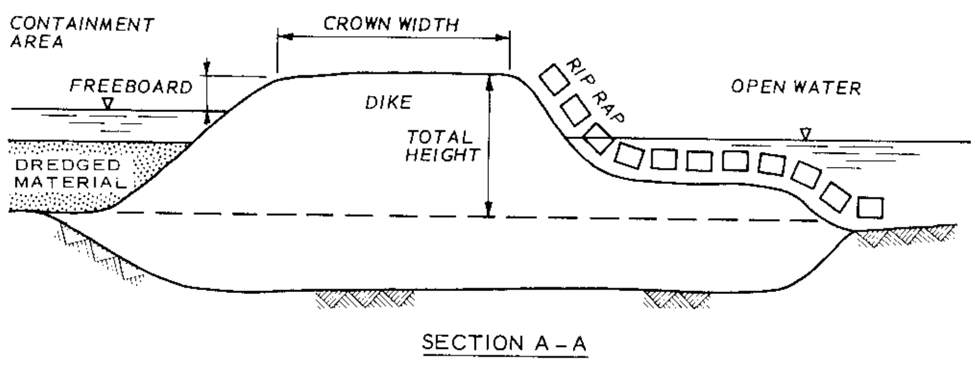


Figure B2. Pertinent features of a dredged material containment area[27] surface of the dredged material begins through evaporation, and a crust begins to form on fine-grained deposits. This crust generally exists at a water content near the shrinkage limit for the material. As desiccation progresses, the thickness of the crust increases; and desiccation cracks extending down to the water table appear. The water table generally remains perched just below the surface and is intermittently recharged by rainfall. The dredged material below the perched water table remains at water contents near or exceeding the liquid limit of the material for years unless something is done to lower the water table and dewater the dredged material.

9. Figure B3 shows the relationship between water content and volume of fine-grained dredged material, while Figures B4 and B5 show crust formation on a deposit of fine-grained dredged material. Further information concerning the behavior and engineering properties of dredged material in containment areas may be found in the literature cited.[1,28,29]

Dewatering

10. For the productive use of significant volumes of fine-grained dredged material soils to become a reality, these soils will be required

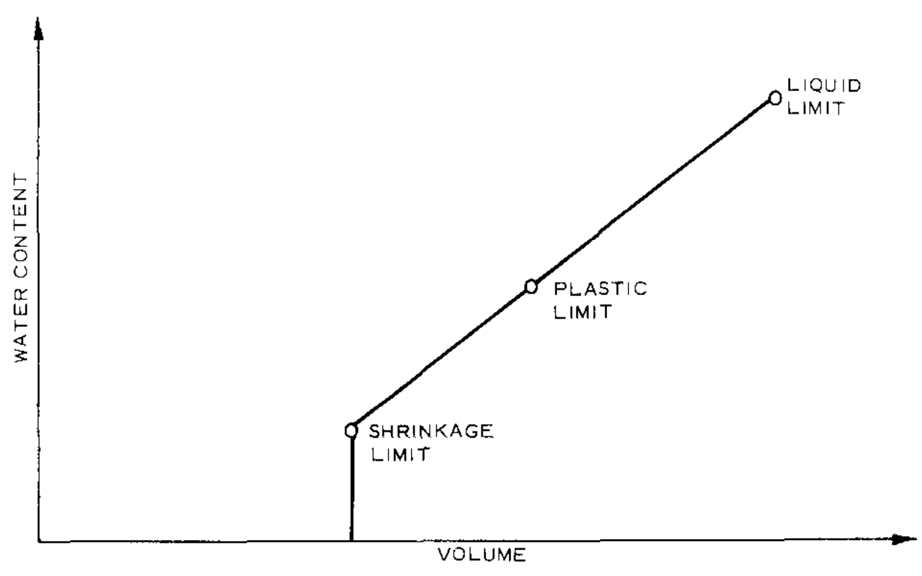


Figure B3. Relationship between water content and volume of fine-grained dredged material[21]

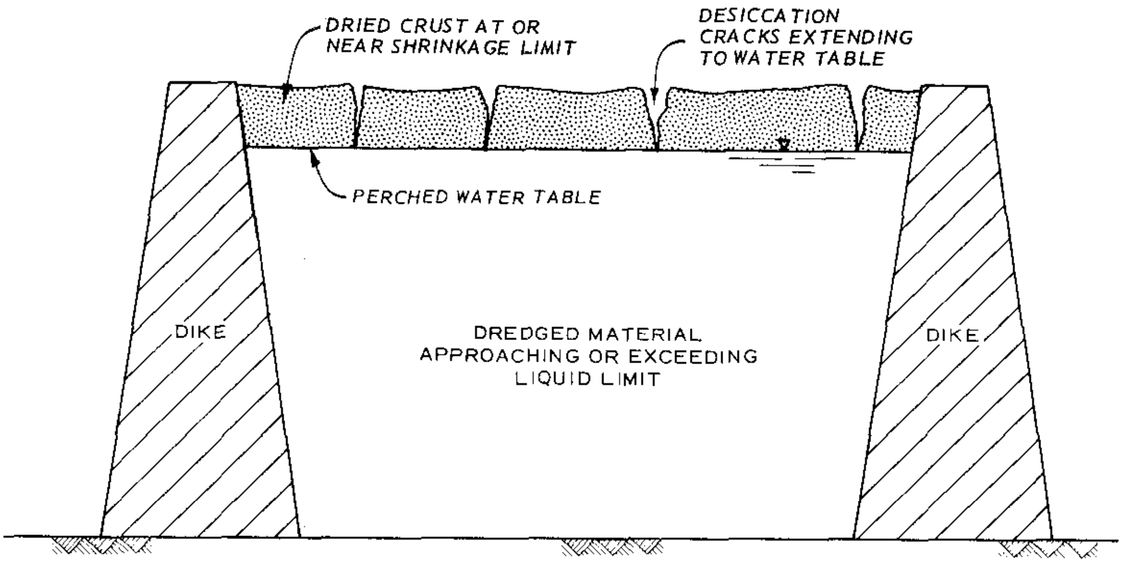


Figure B4. Crust formation on a deposit of fine-grained dredged material[21]

to exhibit engineering properties similar to those of natural soils. To exhibit such properties the dredged material soils will require dewatering. Dredged Material Research Program (DMRP) findings have shown that dredged material, when dewatered to a water content near optimum, exhibits physical and engineering properties comparable to those of similar compacted natural soils. A major obstacle to the use of fine-grained dredged material in conjunction with solid waste management is the dewatering required to improve the physical and engineering properties to the point where fine-grained dredged material is comparable to natural compacted soil.

11. Several investigations into the dewatering and densification of fine-grained dredged material are being conducted as part of the DMRP. Specific techniques being studied include surface trenching, conventional dewatering (underdrainage, vacuum well points, surcharging, etc.), crust management, electro-osmosis, and wicking. Discussion of each of these techniques is beyond the scope of this study.

Figure B5. Desiccation cracks on the surface of fine-grained dredged material

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Bartos, Michael J

Use of dredged material in solid waste management / by Michael J. Bartos, Jr. Vicksburg, Miss. : U. S. Waterways Experiment Station, 1977.

63, [14], 8 p. : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; D-77-11)

Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C., under DMRP Work Unit No. 4C02.

References: p. 61-63.

1. Dredged material. 2. Dredged material disposal. 3. Sanitary fills. 4. Slurries. 5. Solid wastes. 6. Waste disposal. I. United States. Army. Corps of Engineers. II. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; D-77-11.

TA7.W34 no.D-77-11